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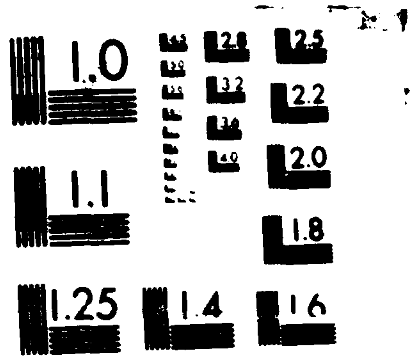

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CONTRACT REPORT BRL-CR-563

LASER BALLISTIC SENSOR DEVELOPMENT

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BOEING AEROSPACE COMPANY
MS 8C-64
PO BOX 3999
SEATTLE, WASHINGTON 98124

JANUARY, 1987

US ARMY BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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19. Abstract (continued)

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As a result of the test, the following problem areas have been identified: 1) The test results show that a system with a higher dither frequency must be developed, 2) The use of two independent lasers complicate the alignment procedure. It would be more reasonable to use a two-color laser (e.g. argon ion laser), 3) Some of the data contains an intensity variation at the fundamental of the dither frequency. This could be due to the projectile lying at the edge of the "overlap" of the dithered beams. A larger beam should eliminate this problem and simplify the alignment procedure, 4) The reflection coefficient versus angle was assumed to be sinusoidal for the present data reduction algorithm. In practice, the reflection coefficient is not sinusoidal, and the shape of the function changes with relative humidity and laser wavelength. Additional development is needed on an algorithm based on a more realistic analytic model.

ACKNOWLEDGEMENTS

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SUMMARY

The prototype instrument to determine the orientation of a projectile in free flight (i. e. roll, pitch and yaw angles) was developed at Boeing and used to perform tests at the U.S. Army Ballistic Research Laboratory (BRL) at Aberdeen Proving Ground, MD. The instrument incorporated two visible gas lasers (to provide a two color collimated illuminating beam) and a pair of galvanometer beam deflectors to generate a circular angular dither of the output beam. All three angles can be determined from the detected light reflected by a retroreflector/hologram combination mounted on the projectile. The prototype instrument was designed to make three-axis angle measurements on in-flight or in-bore spinning or non-spinning projectiles, and to make two-axis angle measurements of gun tube motion.

Tests were performed by both Boeing and BRL personnel at the Aerodynamics Range at BRL during a two week period in August, 1985. The test instrumentation was then left at BRL for additional testing by BRL personnel. A summary of the test results follows: 1) All three angles of a spinning projectile can be measured with a fixed beam and two detectors, where one detector senses fringe amplitude and the other detector senses roll, 2) The dither rate (3 kilohertz) was too low for the non-spinning projectiles tests, 3) No in-bore data was obtained due to obturation, 4) Dynamic measurements of both angle and position of a gun tube were demonstrated.

As a result of the test, the following problem areas have been identified: 1) The test results show that a system with a higher dither frequency must be developed, 2) The use of two independent lasers complicate the alignment procedure. It would be more reasonable to use a two color laser (e.g. argon ion laser), 3) Some of the data contains an intensity variation at the fundamental of the dither frequency. This could be due to the projectile lying at the edge of the "overlap" of the dithered beams. A larger beam should eliminate this problem and simplify the alignment procedure, 4) The reflection coefficient versus angle was assumed to be sinusoidal for the present data reduction algorithm. In practice, the reflection coefficient is not sinusoidal, and the shape of the function changes with relative humidity and laser wavelength. Additional development is needed on an algorithm based on a more realistic analytic model.

INTRODUCTION

This document is the final report on Phase 1 of contract DAAK11-84-C-0095. The contract is the first part of a program whose goal is to develop hardware for measuring the angular orientation of projectiles in-flight and in-bore, and the angular response of gun tubes during firing. The technology, originally developed for measuring the pitch angle of models in the Boeing Transonic Wind Tunnel, was shown to be applicable to spinning projectile yaw angle measurement in a prior test program (Reference 2) at the U.S. Army Aerodynamics Range. Significant improvements to the measurement techniques were made in the present contract.

A two-laser breadboard system was assembled at Boeing for evaluation at the Ballistic Research Laboratory. The breadboard was designed to make 3-axis angle measurements on in-flight and in-bore non-spinning or spin-stabilized projectiles, and 2-axis angle measurements on gun tubes. For spin-stabilized projectiles, three-axis angle measurements were demonstrated. Signals were obtained from non-spinning projectiles, but could not be converted into meaningful information due to the inability of the breadboard optical system to measure the orientation of projectiles possessing high yawing rates. No in-bore data was obtained due to degradation of the incident laser beam quality resulting from the leakage of hot combustion gases around the projectile. Dynamic measurement of both angle and position were demonstrated for the gun tube tests.

The report contains a description of the breadboard system, the modifications required for the various measurement tasks, the test conditions, and the test results. Data reduction algorithms developed by Boeing are in Appendix B. Preliminary design information for Phase II hardware, based on the results of this evaluation, are included.

OPTICAL TEST SET-UP

The test setup consists of an optical unit and supporting electronics located in the range together with data acquisition and processing equipment placed in the control room. The optics will be discussed first.

Figure 1 shows the arrangement of optical elements on a standard 0.6x1.2 meter setup board. Red and blue lasers are used to provide orthogonal angle measurements on the projectile. The beams are combined in a dichroic cube beamsplitter and then directed to the filter-splitter. A lens in the red beam is used to adjust the beam diameter at the filter-splitter so that the red and blue beams have the same diameter when they exit the unit.

The filter-splitter is a Boeing device (U. S. Patent No. 4,329,059) that spatially filters the outgoing beam while transmitting most of the return beam energy to the photodetectors. The coaxial red and blue beams at the input to the filter-splitter are focused by a microscope objective lens onto a small elliptical mirror on a tilted glass plate which spatially filters the reflected beams and insures that the red and blue beams are collinear. The elliptical mirror is small compared to the diffraction pattern of the return beams from the reflector on the projectile, so more than 90% of the return energy passes on to the photodetectors.

A two-axis galvanometer type beam deflector generates a circular dither (or conical scan). The relay lens forms an image of the filter-combiner mirror in the focal plane of the large collimating lens. The function of the relay lens is to reduce lateral motion of the spot at the projectile. (The translation is zero in the plane where the combination of the collimating and relay lenses forms an image of a galvanometer mirror.) The output beam is collimated and reflected into the projectile path with a pair of mirrors (not shown).

The reflector assembly consists of a hologram and a cube corner reflector, as described in Reference 2, with modifications that allow 3-axis angle measurement. The hologram has a central circular holographic grating surrounded by an annular grating with equal area but orthogonal fringe orientation. Red and blue spectral filters that match the hologram profiles are sandwiched between the hologram and the reflector.

The circular dither on the outgoing beam produces orthogonal sinusoidal components to match the axes of the dual hologram. Amplitude and phase of a pair of dither frequency harmonics (for each color) are used to find the orientation of the projectile body axis. Roll about the body is proportional to the phase difference between the deflector driver and the fundamental component of the return signal.

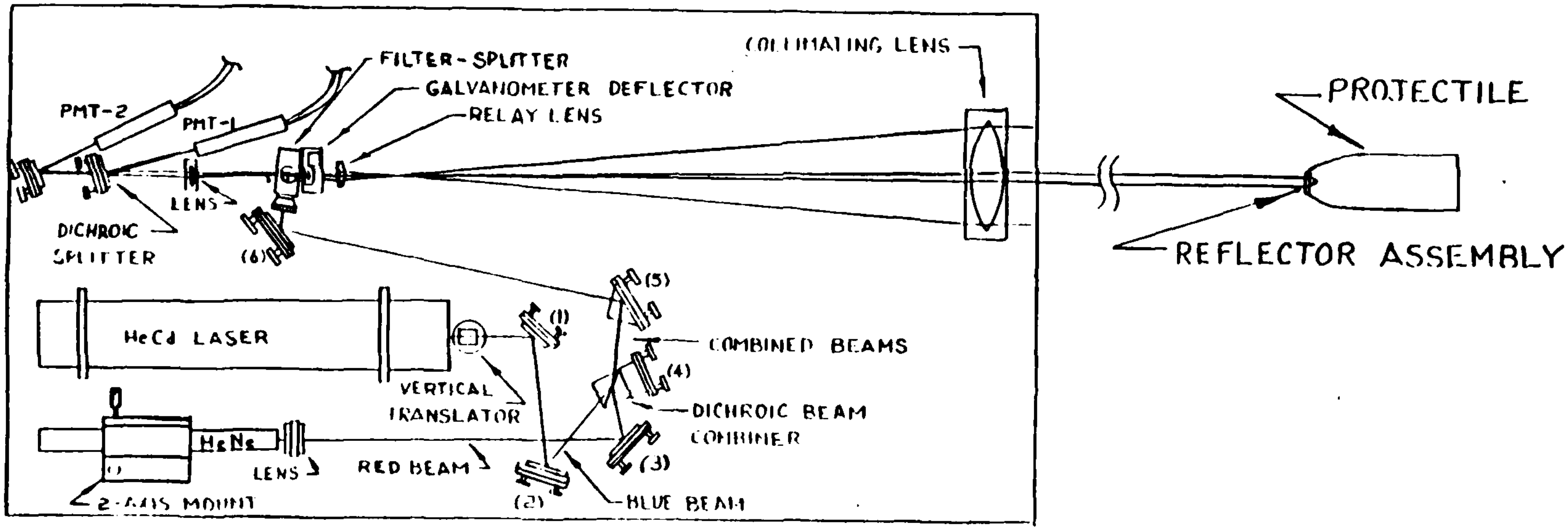


Figure 1. BRL Optical Breadboard.

DATA ACQUISITION ELECTRONICS

Figure 2 is a block diagram of the data Acquisition Electronics (DAE). The DAE was used to collect range or calibration data. The photodetectors were Hamamatsu R761 photomultipliers (PMT), a head-on type with a half inch (13mm) diameter photocathode. The PMT has ten dynode stages, typical current gain of 5.8X10E+5, and a spectral response from 185nm to 850nm, peaking at 420nm. The light entering the PMT's was optically filtered for the two optical wavelengths before application to the PMT's.

Both the red and blue signal channels are identical with the exception of the overall gain. Load resistors for the PMT's were 10k ohms. At the optical assembly each PMT output was amplified by a HP465A amplifier with a gain of 20db and filtered by a Krohn-Hite 3342 filter/amplifier. One section of the Krohn-Hite filter is used as a low pass filter with a cutoff frequency of 100Hz and a gain of 20db. The low pass section drives the high pass section resulting in a bandpass with cutoff frequencies of 100Hz and 24KHz. The high pass section of the Krohn-hite filter drives approximately 100 feet of terminated coax cable between the optical assembly and the control room. The variable gain capability of the HP467A was used to adjust the input amplitude to the tape recorder and analog-to-digital converter to approximately one volt RMS.

All timing for the system is synchronously derived from a very stable frequency source, an HP8460B signal generator operating at 576Khz. Quadrature (i.e. the two signals are out of phase by 90 degrees) signals at 3Khz drive the elevation and azimuth galvanometers.

An EMI7000 tape recorder was used to record all test data. Each signal output from the HP467A's was applied to three tape recorder channels and one channel of the ADC/Computer Interface. The gain settings of the three tape recorder channels were adjusted to accommodate signals that were the expected nominal and plus and minus 50% from nominal. Other sources of data recorded by the EMI7000 are shown in Figure 2.

The direct memory access, DMA, of the HP9836 computer was used as a transient waveform recorder to collect real time range and calibration data for immediate and future data reduction. All four channels of the ADC/Computer Interface are sampled synchronously at a 36Khz rate and data transferred to the computer by DMA at 144 kilobytes.

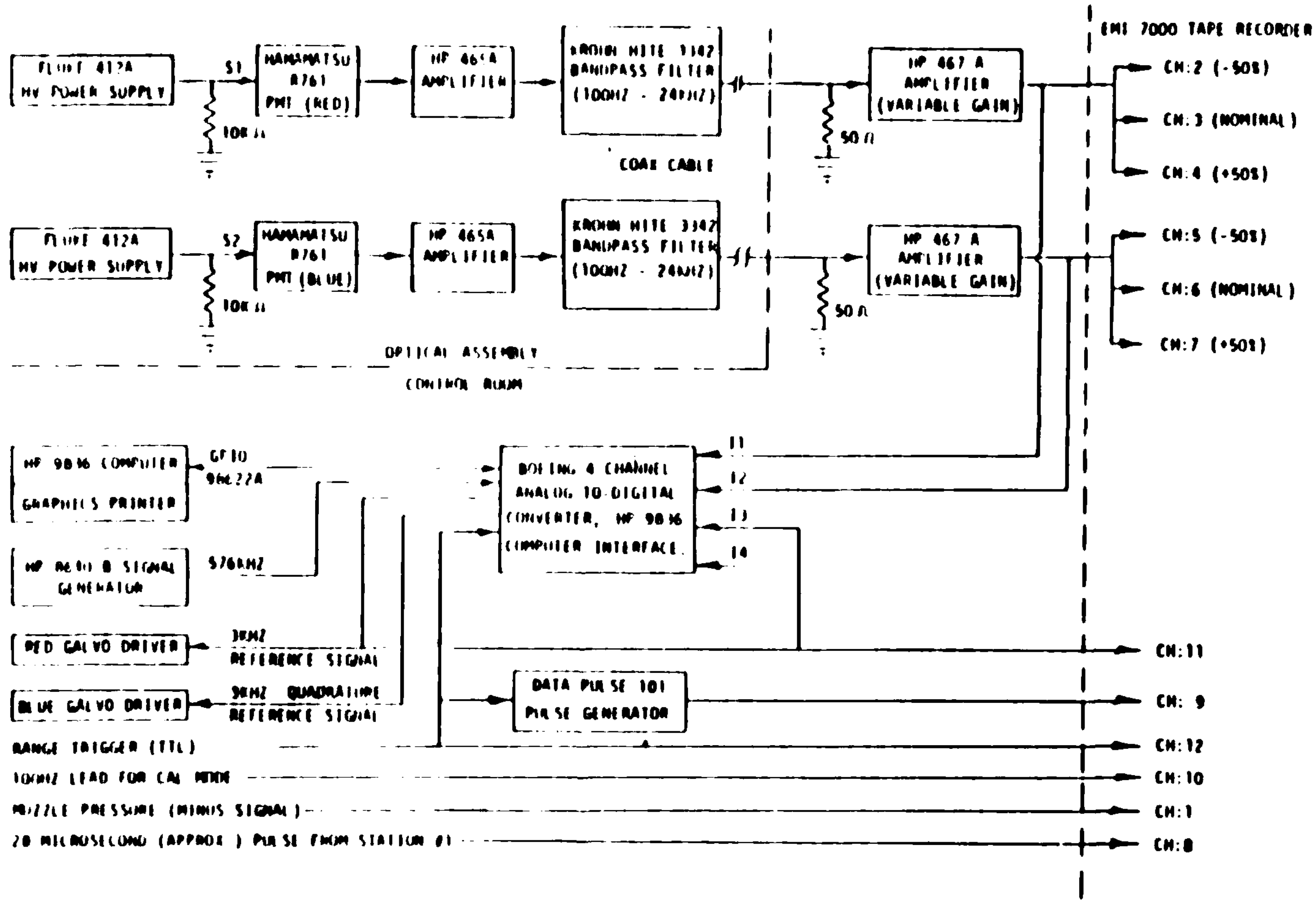


Figure 2. Block Diagram of Data Acquisition Electronics.

Initiation of range data collection was synchronized to the first positive crossing of the 3Khz signal driving the red galvanometer after a range trigger is received. This synchronization was incorporated to facilitate the phase measurement required in processing the data. When range data was collected, the red, blue, and 3Khz reference signals were sampled and stored by the computer.

Each hologram/retroreflector combination was calibrated by placing it in a test fixture which allowed it to be rotated in two orthogonal planes, simulating pitching and yawing motion. During this procedure the red and blue signals and the x and y positions of the gimbal positioning device were also sampled and stored by the computer. Appendix A contains the schematics for the data acquisition electronics.

DATA PROCESSING

Since data processing is dependent on the characteristics of the holographic grating and corner reflector combination, the reflector assembly will be described first.

The reflector assembly, Figure 3, consists of a holographic grating and a cube corner reflector. The reflector assembly is small and rugged with typical dimension of 6.4 mm diameter and 5 mm high. The input light beam is diffracted by the hologram into the zero and higher order beams. For clarity, only the zero order and one of the signed first order beams are shown in the figure. These two beams are retroreflected by the cube corner and again diffracted by the hologram. Note that the zero and first order beams are again diffracted into zero order and first order beams. The emerging composite zero order consists of a number of parallel component beams. These component beams follow different optical paths, consequently they interfere constructively or destructively, depending on relative phase difference. Figure 4 shows the modulation of the reflection coefficient due to optical interference as a function of the angle of incidence.

The resulting fringe angle of the hologram corner cube combination is dependent on the fringe angle of the hologram when it is produced, the index of refraction and height of the corner cube reflector. Figure 5 is a diagram showing the optical set up for producing the hologram. The diffraction angle for the hologram is

$$\Theta_d = 2 \sin^{-1}(\lambda/2s)$$

where λ is the wavelength of the laser source and s is the grating period.

The fringe angle for the hologram and corner cube reflector combination is approximately

$$\Theta_f = n\lambda/2h\Theta_d$$

where h is the height and n is the index of refraction of the cube corner reflector.

If the change in angle of the retroreflector is unidirectional then the amplitude of the reflection coefficient could be used to measure the angle of the retroreflector. In reality the amplitude does change due to effects other than changes in the angle of the cube corner reflector (e.g. noise, changes in laser power output). To determine the direction of change of the retroreflector angle, quadrature signals are required. With quadrature

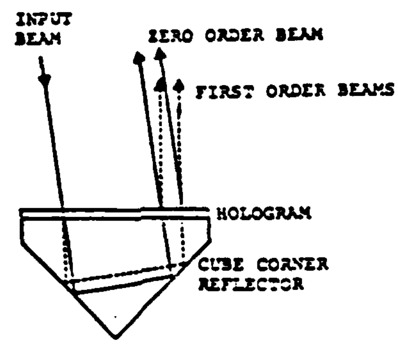


Figure 3. Reflector Assembly.

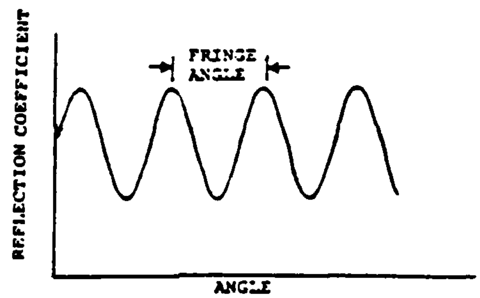


Figure 4. Reflection Coefficient.

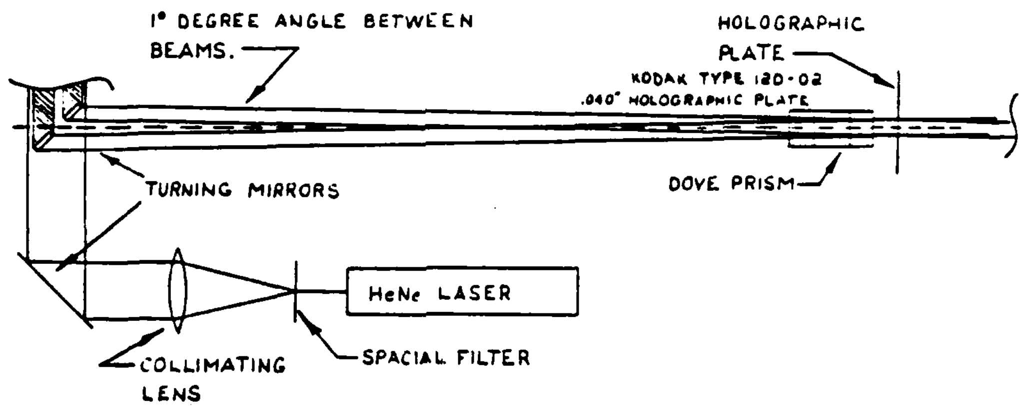


Figure 5. Technique used in making a 1^0 Diffraction Angle Hologram.

(i.e. signals are out of phase by 90°) signals phase can be measured, direction of phase change determined, and the amplitude effects which are not related to angle can be eliminated.

The spin of a spinning projectile provides the modulation which enables data reduction. For a slow spin or non-spinning projectile the laser beam is dithered (angle modulated) in order to change the incident angle of the input light beam at the retroreflector. This is accomplished by the azimuth and elevation galvanometers and beam directing optics.

Angle modulation of the beam across the fringe pattern shown in Figure 4 results in quadrature relationships existing between frequency components of the photodetector current which are harmonicly related to the modulating frequency. Figures 6 through 8 support the analytical description to follow from which the software algorithm was developed. This analytical description is for one axis only and is not as rigorous as the description for the analytic model which was developed at the end of the program.

Figure 6a represents the photodetector output (equivalent to the reflection coefficient) and Figure 6b the angle modulation at the dither frequency. Figure 6c is the photocurrent for the angle modulation shown in Figure 6b. I is the photodetector current output as a function of the angle of the corner cube reflector and $\theta_r = 2\pi$ (yaw angle)/(fringe angle). Ip is one half the peak-to-peak value of the photodetector current and t is time. m_p is the peak deviation of the angle modulation in radians and w_m the modulation frequency of the dither in radians per second.

The equations that describe the modulation effects of the dither are

$$
\begin{aligned}
I(\theta_r, t) &= I_p \sin(\theta_r + m_p \sin w_m t) \\
&= I_p \sin \theta_r \cos(m_p \sin w_m t) + \\
&\quad I_p \cos \theta_r \sin(m_p \sin w_m t) \\
&= I_p \sin \theta_r \, [J_0(m_p) + 2J_2(m_p)\cos 2\, w_m t + \\
&\quad 2J_4(m_p)\cos 4w_m t + \ldots] + \\
&\quad I_p \cos \theta_r \, [2J_1(m_p)\sin w_m t + 2J_3(m_p)\sin 3w_m t + \ldots]
\end{aligned}
$$

where the values of $J_n(m_p)$ are determined from the graph of Bessel Functions, Figure 7. Note that the amplitudes of the odd and even harmonics above are quadrature functions. The amplitude of the odd harmonics is proportioned to the cosine of θ_r and the amplitude of the even harmonics is proportional

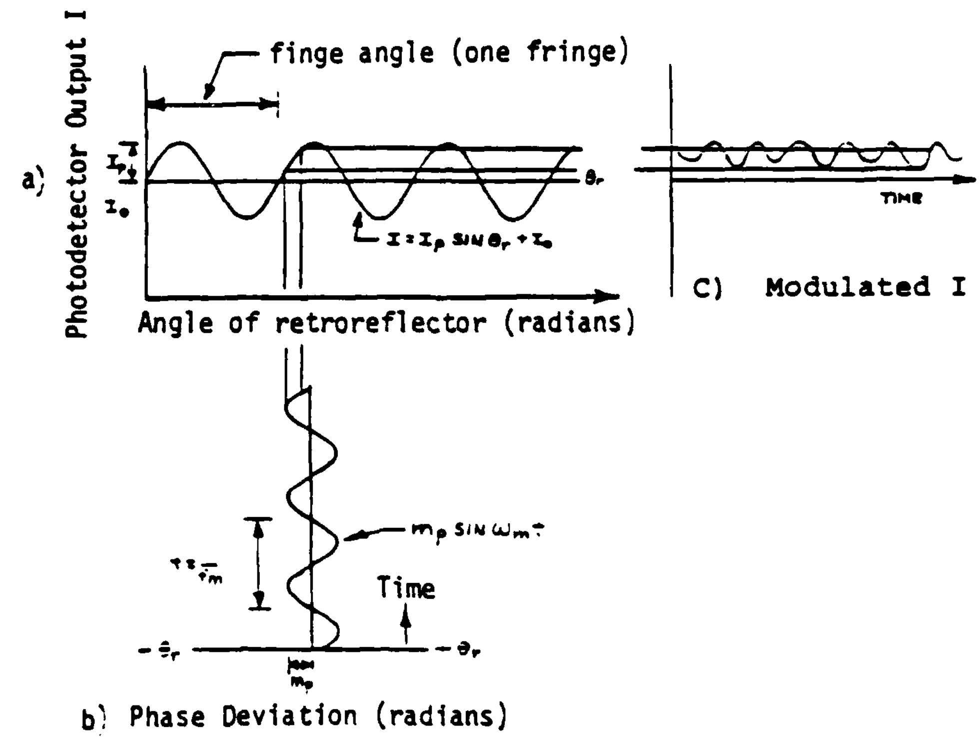


Figure 6. Angle Modulation of the Fringe Angle.

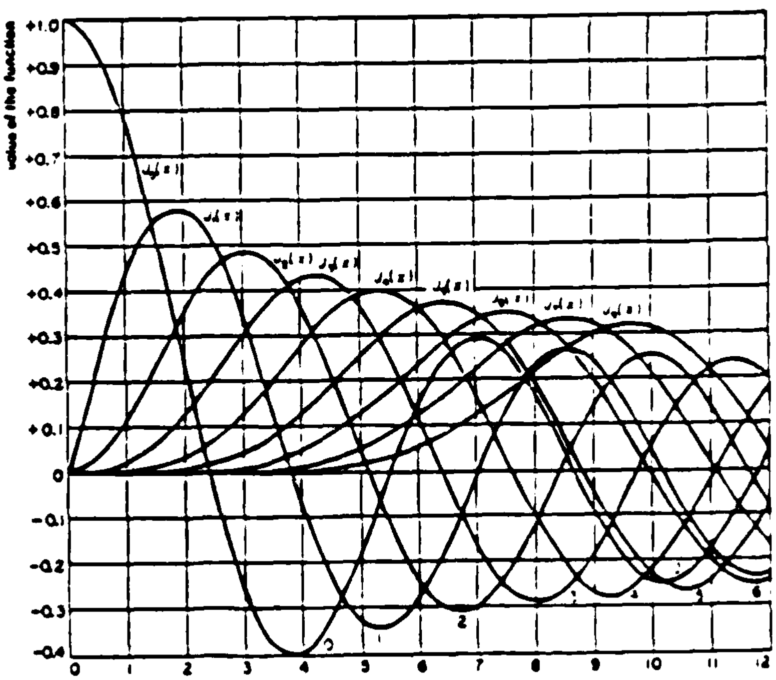


Figure 7. Bessel Functions for the first 8 orders.

to the sine of the θ_r. The fundamental and second harmonic were used in the breadboard system.

Figure 8a is the photodetector output with a graphic representation showing the relation between the fundamental and second harmonic components of a reflected beam for a small value of m_p. The figure shows the relationship between the reflected signal and the dither signal, when $\theta_r = 0, \pi, 2\pi, \cdots$. The fundamental frequency dominates the signal when $\theta_r = 0, \pi, 2\pi, \cdots$. The second harmonic dominates the signal when $\theta_r = \pi/2, 3\pi/2, 5\pi/2 \cdots$. Note the Pi radian phase reversal between the positive and negative slopes for the fundamental and the positive and negative peaks for the second harmonic. Figure 8b and c are the fundamental and second harmonic filtered from the photodetector current by bandpass filters. The amplitude factor m_p is chosen equal to approximately .27 resulting in equal peak-to-peak amplitudes for the fundamental and second harmonic. It is important to note that the waveforms of the fundamental and second harmonic are in quadrature.

Figure 8d shows the desired quadrature terms as a function of cube corner reflector angle. To arrive at these outputs a phase comparison must be made between the fundamental and the modulating frequency for the fundamental, and between the second harmonic and twice the modulating frequency for the second harmonic. Devices such as balanced mixers used as a phase detector, followed by a suitable low pass filter, would produce the desired output. For the computer algorithm the envelope amplitude and sign is determined for each cycle of reference phase.

After amplitude and phase detection the quadrature signals of Figure 8c and d can be written as

$$E_1(\theta_r) = I_p(2J_1(m_p))\cos\theta_r$$

$$E_2(\theta_r) = I_p(2J_2(m_p))\sin\theta_r$$

where $E_1(\theta_r)$ is the detected envelope of the fundamental and $E_2(\theta_r)$ the detected envelope of the 2nd harmonic. Then

$$E_2(\theta_r)/E_1(\theta_r) = I_p\ 2J_2(m_p)\sin\theta_r / I_p\ 2J_1(m_p)\cos\theta_r$$

$$= J_2\sin\theta_r / J_1\cos\theta_r = (J_2/J_1)\tan\theta_r$$

and

$$\theta_r = \tan^{-1}[J_1E_2(\theta_r)/J_2E_1(\theta_r)]$$

The sign of the argument of the arctan identifies the quadrant for each quarter-fringe cycle. Comparison of the signs of the numerator and denominator of the present and previous measurements are used to identify quadrant boundary

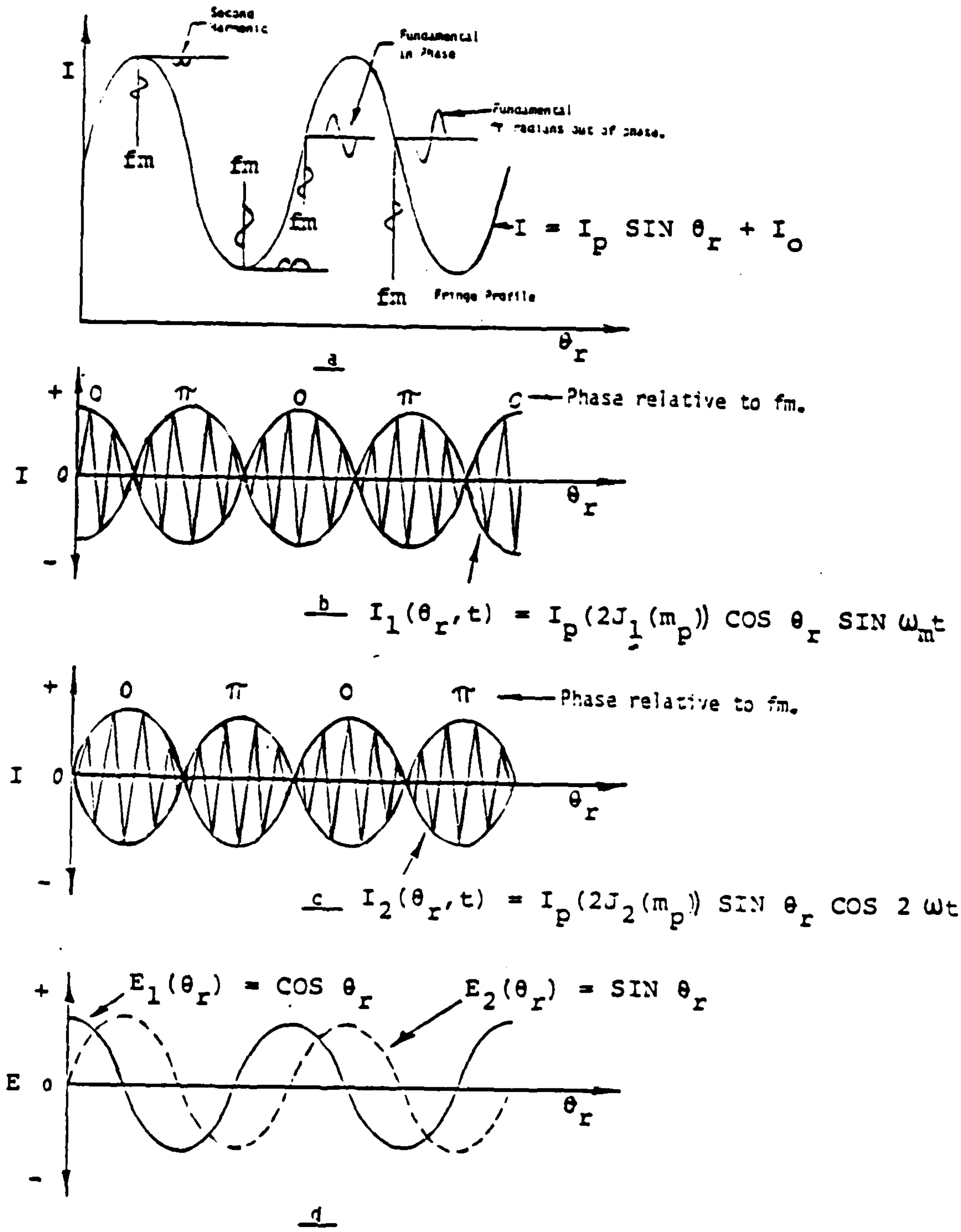


Figure 8. Modulated and Detected Waveforms.

crossings. Consequently, fractional fringe quarter cycles can be measured, and the boundary direction crossing used to sum quarter fringe cycles.

SOFTWARE DEVELOPMENT

Software was developed using the preceding analytical description. It is important to note that the software was a development effort intended for diagnostics and for the future determination of the requirements for complete data reduction by a HP9836 computer or the range computer.

The two programs (written in the BASIC language) are included as Appendix B. One software program is used for collecting and processing range data when a range trigger is received and the other is used to collect calibration data for a given hologram cube corner reflector combination. The calibration program was derived from the range program, consequently parts of the program are not integral to the calibration process. Figure 9 is the flow chart for the range data collection and processing program.

Range data consisted of the outputs from the two photomultipliers and a 3Khz reference (the 3Khz signal driving the elevation galvanometer). For each cycle of the 3Khz reference there are twelve data samples for each channel of the ADC/Computer Interface. Transfer of data was done using the Basic TRANSFER command. Data was transferred to a DMA Buffer in real time for a predetermined time after receiving a range trigger. At the end of this predetermined time, determined by the DMA Buffer size, the binary data was converted to decimal and placed in a program array for use by the program.

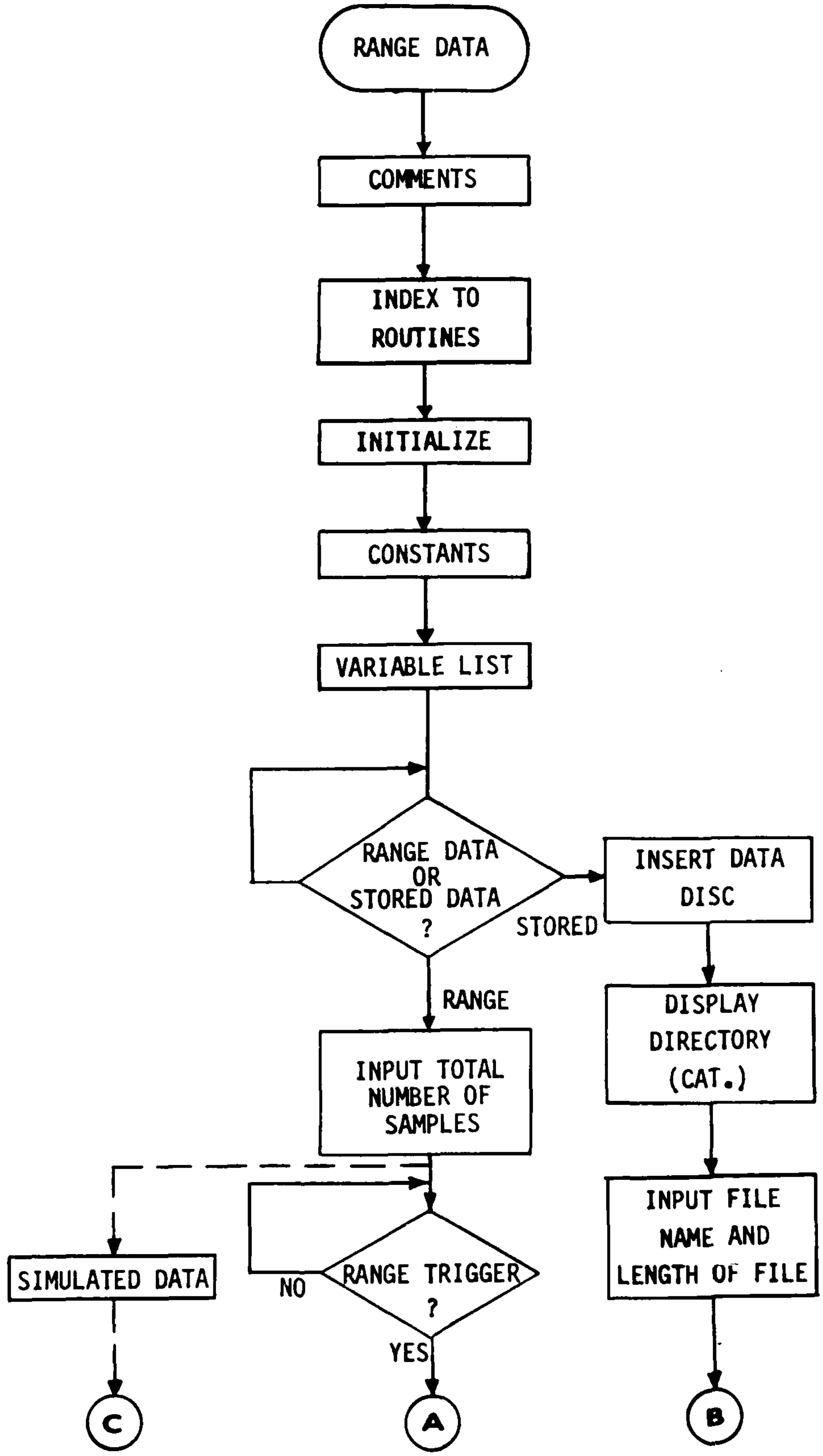


Figure 9. Computer Program Flow Chart

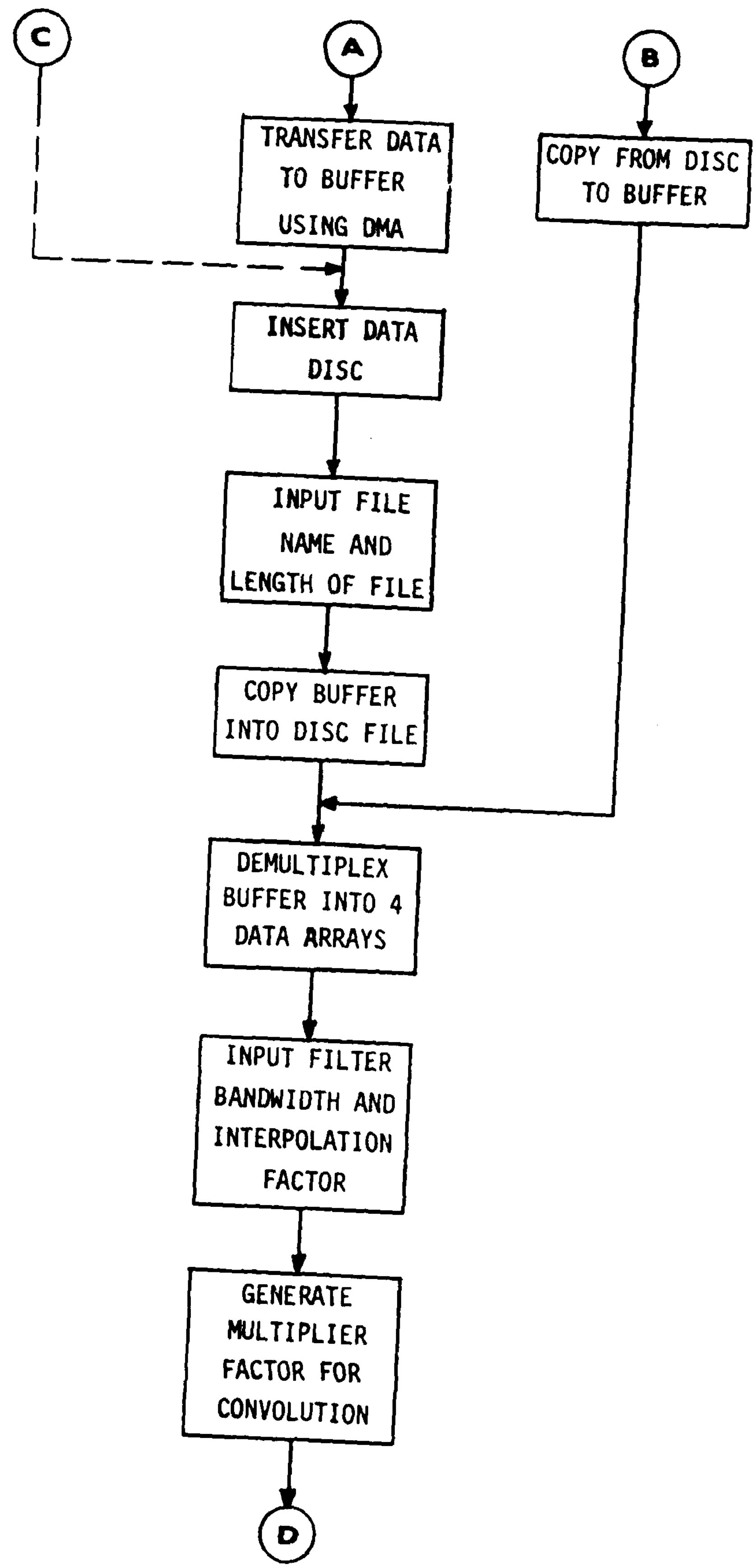


Figure 9. Computer Program Flow Chart

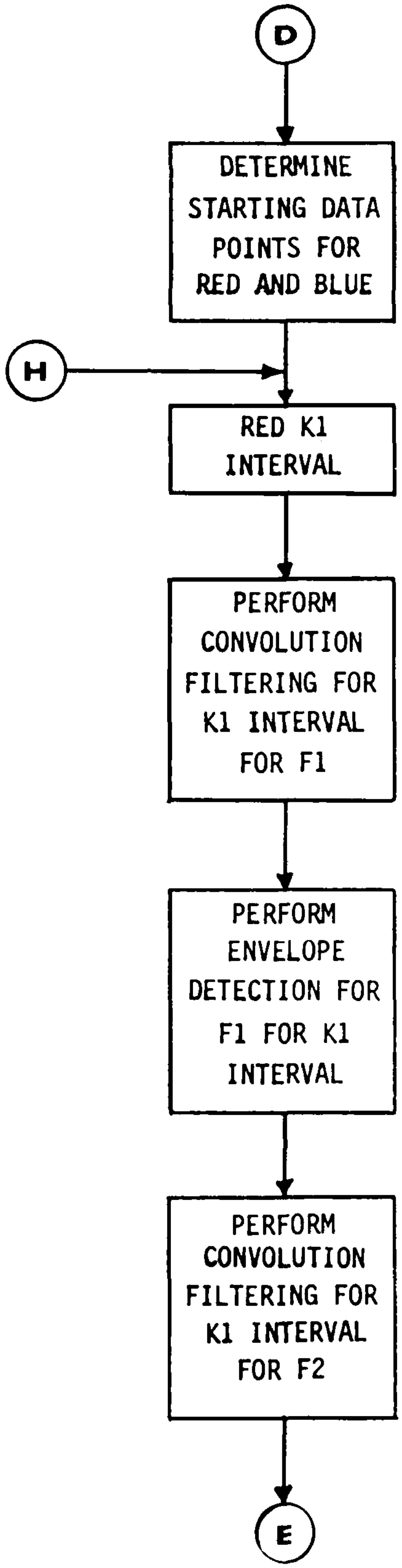


Figure 9. Computer Program Flow Chart (continued)

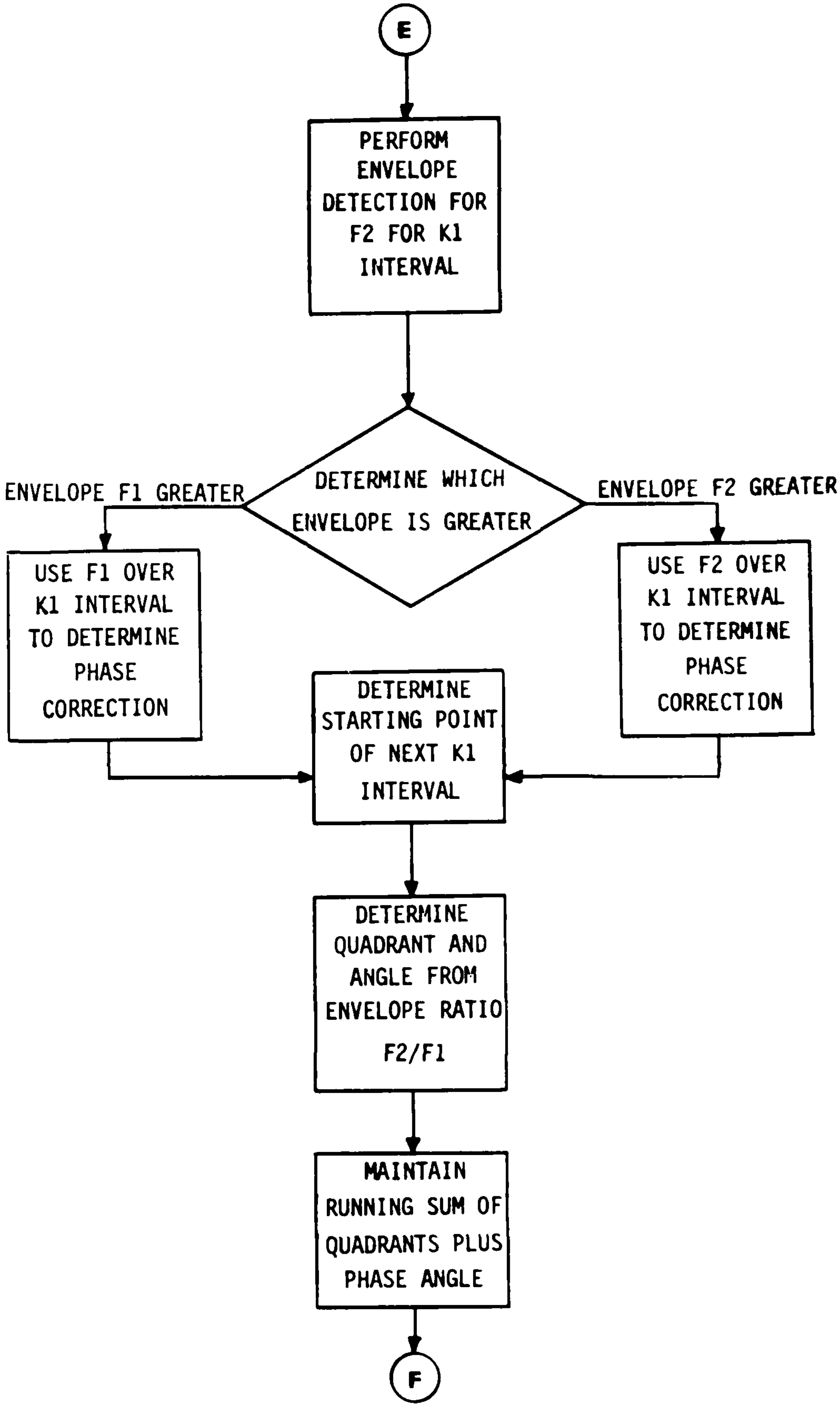


Figure 9. Computer Program Flow Chart (continued)

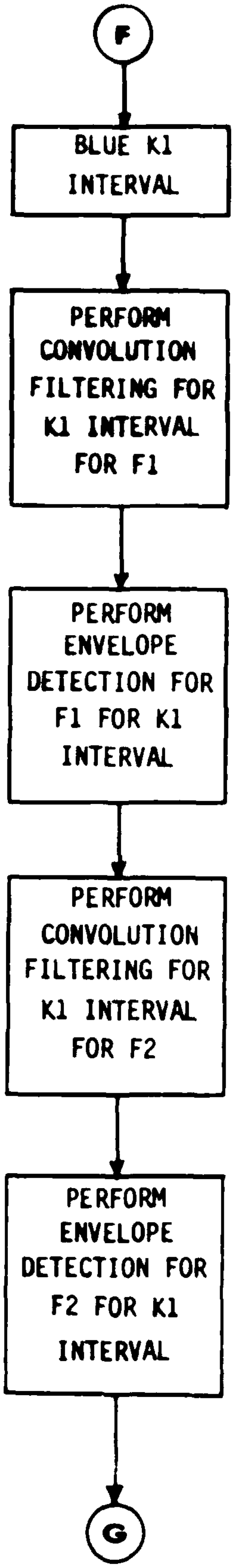


Figure 9. Computer Program Flow Chart (continued)

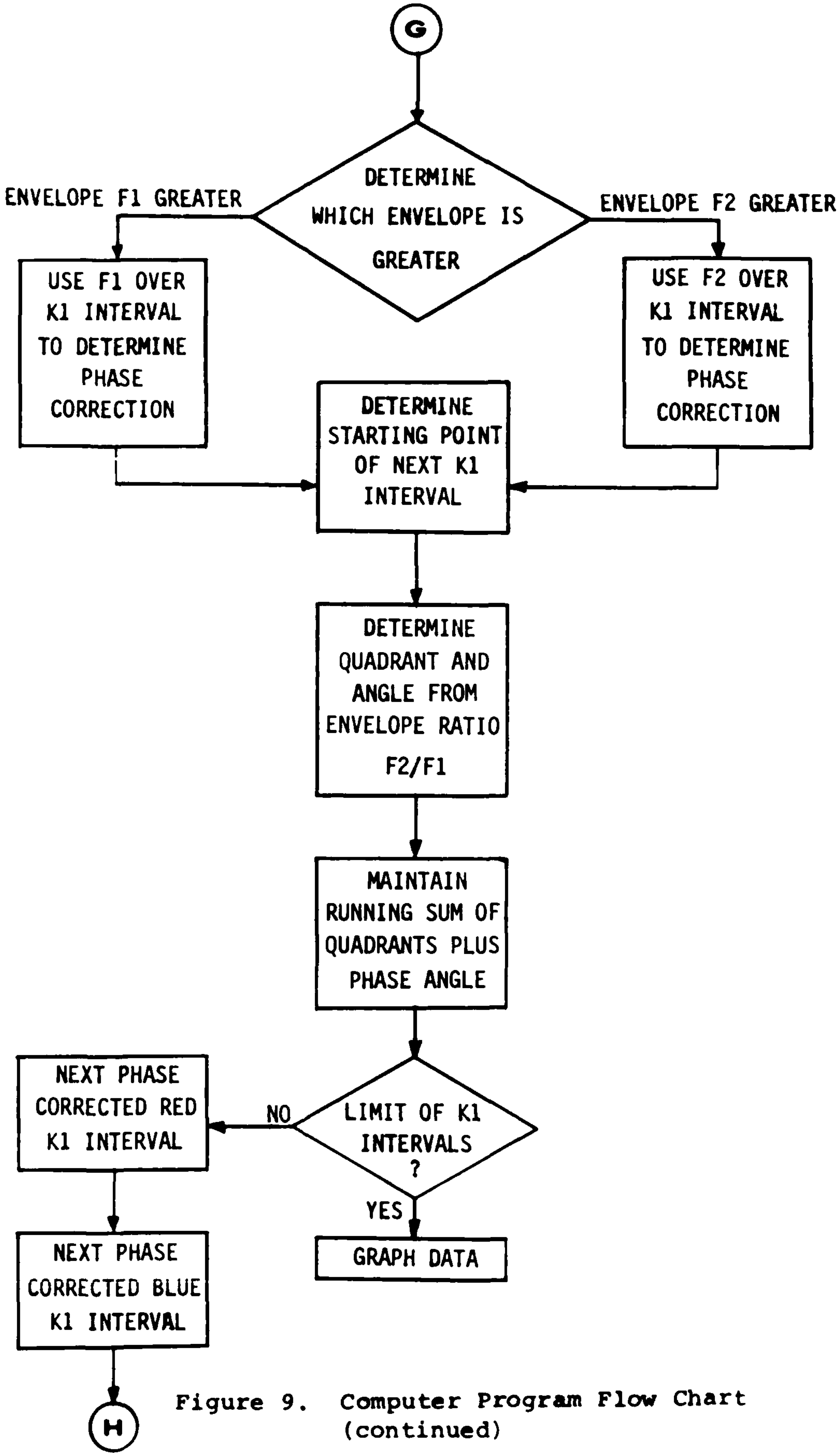


Figure 9. Computer Program Flow Chart (continued)

TEST RESULTS

The test configuration and results of tests performed jointly by BAC and BRL personnel are summarized in Table 1 below. Following the table is a discussion of the reduced data listed in the order of those rounds which produced reducible data.

TABLE 1 - ROUND FIRING SUMMARY

NO.	ROUND TYPE	DATA SET	CONFIGURATION	RESULTS
17450	30 mm spinning		Scotchlite on nose, to check for obturation	No range trigger
17452	30 mm spinning	Run-1	Single 1^{o} hologram Red beam set for yaw Blue beam set for roll Flight path 30 m	Data on tape No range trigger
17453	30 mm spinning	Run-2	"	No data No range trigger
		Run-3	No retro, range trigger check	
		Run-4	No retro, range trigger check	
		Run-5	No retro, range trigger check	
17458	30 mm spinning	Run-6	Same as round 17452	Early range trigger No data
		Run-7	No retro, range trigger check	
17460	20 mm no spin	Run-8	2-axis, 1^{o} hologram Cal-3A Flight path 15 m	Data on tape and in computer
17461	20 mm no spin	Run-9 Cal-4	"	"
		Run-10	No retro, range trigger check	
		Run-11	No retro, range trigger check	

TABLE 1 - ROUND FIRING SUMMARY

NO.	ROUND TYPE	DATA SET	CONFIGURATION	RESULTS
17464	30 mm	Run-12 Cal-5	Set up for in-bore measurement. Folding mirror in blast room	No data due to obturation
17465	25 mm	Run-13 Cal-6	Muzzle angle and linear displacement setup. Reflector in collar on muzzle.	Collar moved No data
17466	25 mm	Run-14 Cal-6	"	Displacement and angle data Gun moved back 16mm in last two shots
17467	25 mm	Run-15 Cal-6	"	Muzzle pressure gauge failed
17468	25 mm	Run-16	"	
17469	25 mm	Run-17	"	

Round 17452 - The purpose of this round was to test the feasibility of determining pitch, roll, and yaw angles of a spinning projectile with a fixed beam (no dither). The 30 mm round was fitted with a single 1^{0} hologram and cube corner reflector. The calculated fringe angle is 6 milliradians, based on the hologram diffraction angle and the specified height of the retroreflector.

A retroreflector whose far-field pattern consisted of two spots was used to facilitate roll measurement. The optics for the blue beam were adjusted to form the far-field pattern of the return beam on a slit in front of the photomultiplier so an electrical pulse occurs each time the projectiles rolls 180^{0}. The reflection assembly on a spinning projectile generates a frequency modulated (fm) signal, where the number of cycles per half revolution is proportional to the total yaw angle (Reference 2). The polar angle is proportional to the time between the minimum frequency point of the fm signal (red beam) and the electrical pulse from the blue beam.

Figure 10 shows the laser measurement results of total yaw angle as a function of time. Data obtained from the analysis of a series of orthogonal spark shadowgraphs obtained for this round are shown in Figure 11. The laser measurement is quite similar in shape to the smooth curve fitted to the shadowgraph data. It is interesting that the minimum yaw points at 10m are not on the smooth curve, but they show up on both the raw shadowgraph data and the reduced laser data.

Figures 12a and b are laser and shadowgraph measurements of the horizontal and vertical yaw angle components. The square boxes on the laser curve mark the points at which the pair of far-field blue spots line up with the slit. The projectile rolls 180^{0} between each pair of square boxes, thus the laser angle sensor can measure all three projectile angles.

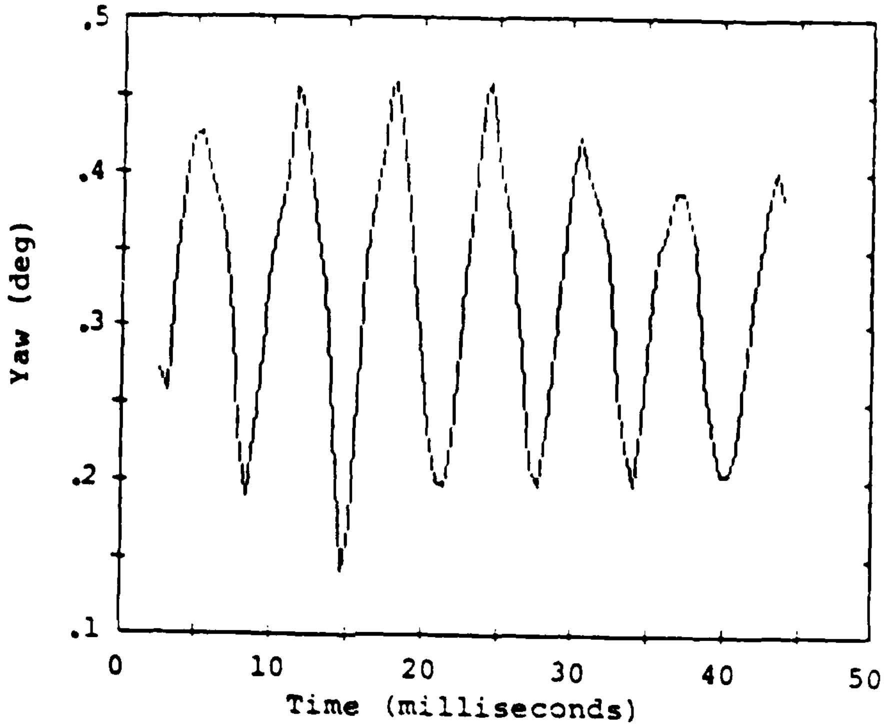


Figure 10. Total Yaw, Round 17452, Laser.

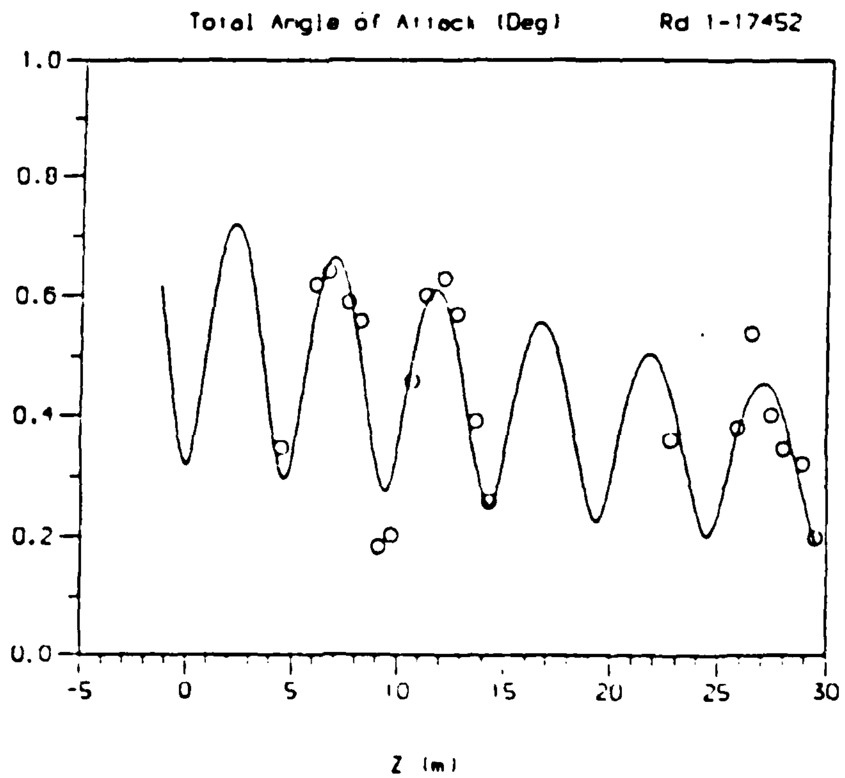
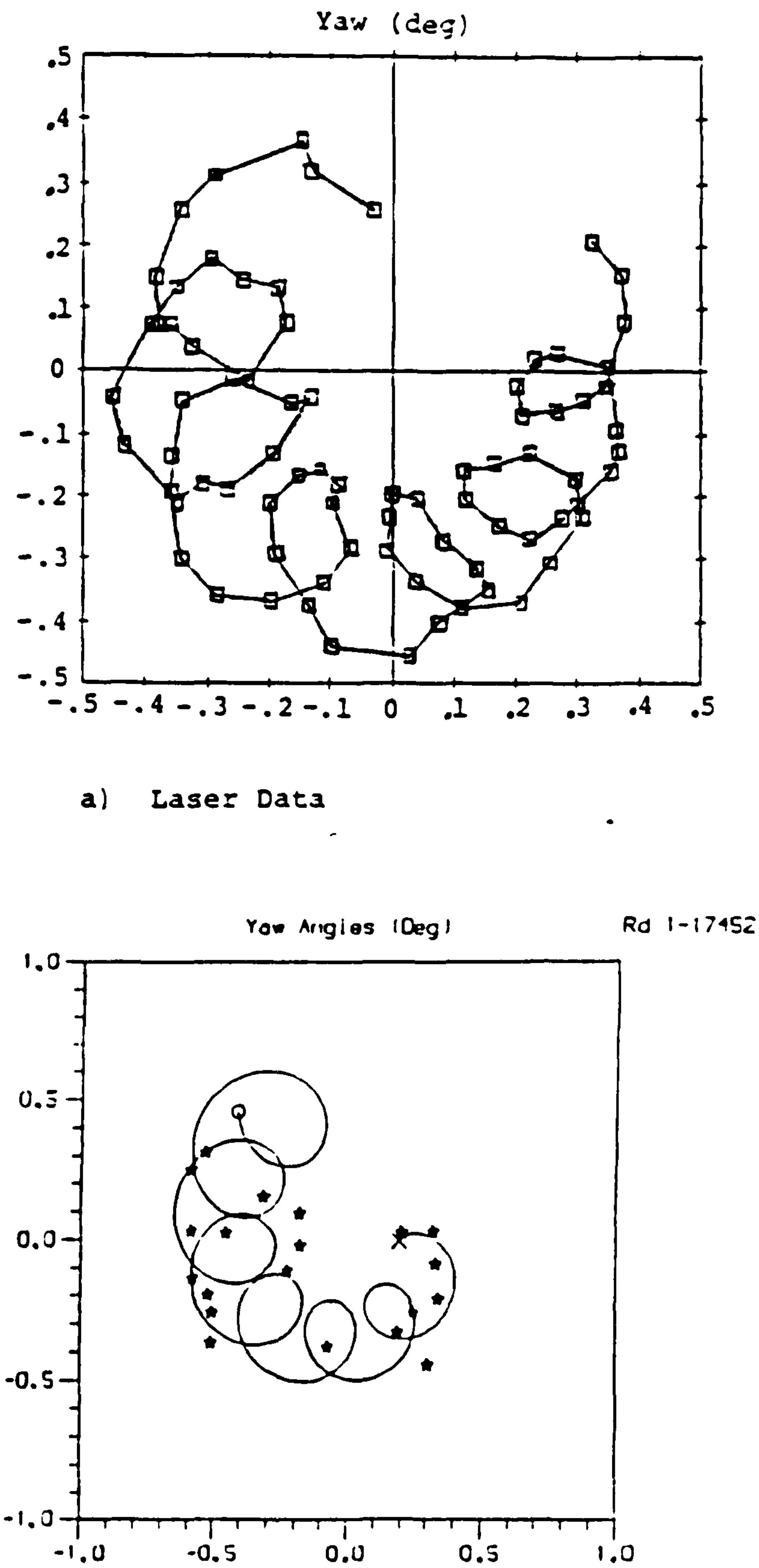


Figure 11. Total Yaw, Round 17452, Shadowgraph.



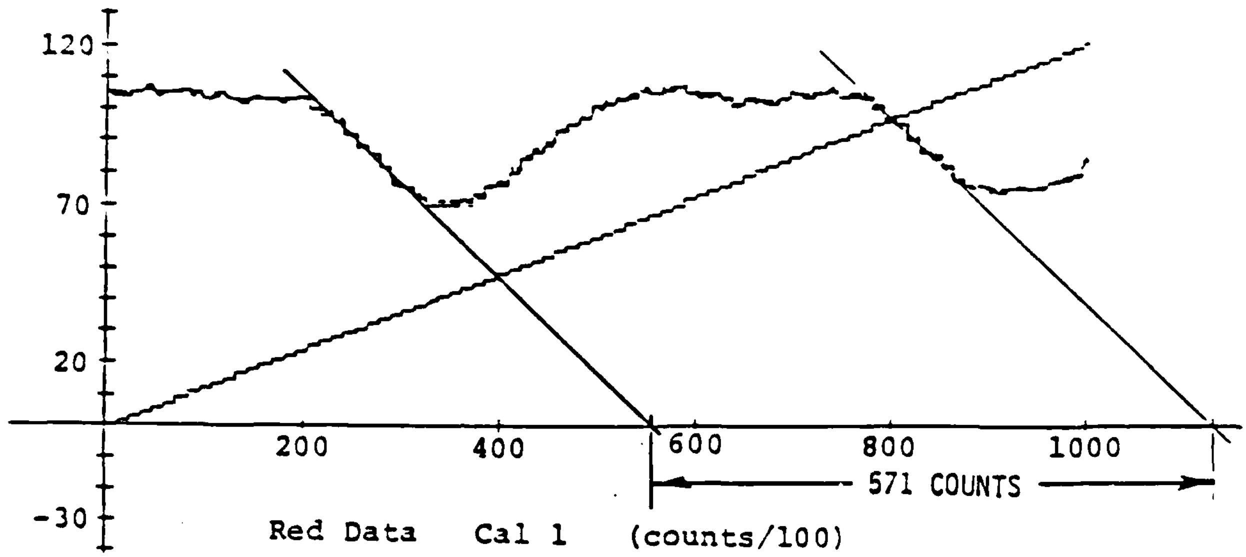
a) Laser Data

b) Shadowgraph

Figure 12. Yaw Angle, Looking Up-range, Round 17452.

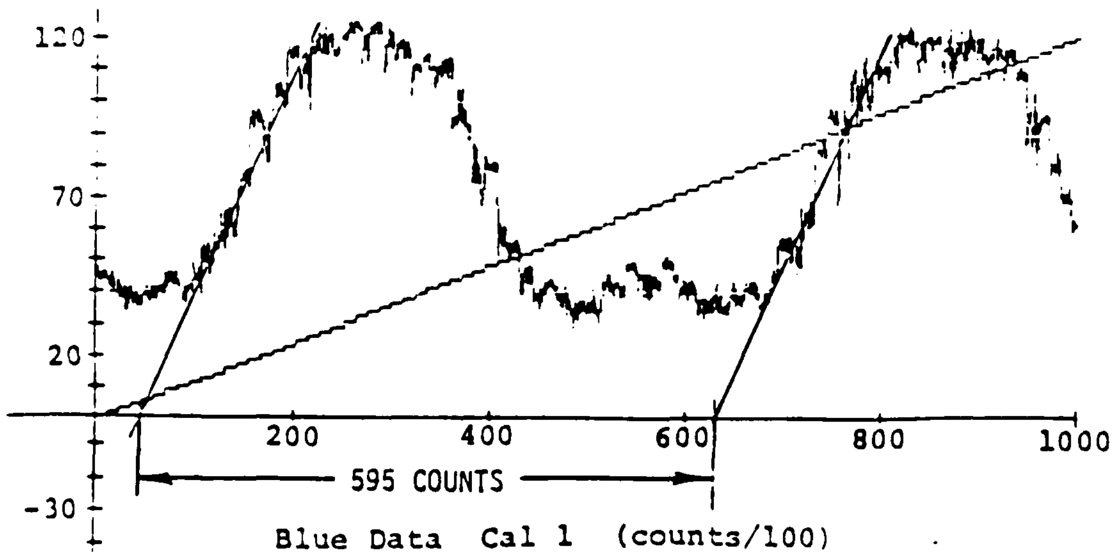
Round 17453 and 17458 - No data was acquired on these rounds due to problems with the range trigger. However, the rounds were calibrated prior to each firing. The calibration technique is described below.

The round is mounted in a precision two-axis motorized optical mount. The mount has a digital encoder that is coupled to the HP-9836 computer. The initial angle is adjusted so that the Fresnel reflection from the reflector assembly returns to the laser. The projectile is rolled so that motion on one axis produces no modulation of the fringes for the orthogonal axis. The mount is then driven slowly and the fringe pattern versus encoder counts is stored in the computer. Figured 13 and 14 show typical fringe patterns. The number of counts per fringe is found by the geometric construction shown on the figure.



1240 COUNTS = 10^{-2} rad
FRINGE ANGLE = 4.61 mrad (0.264 deg.)

Figure 13. Fringe Angle Calibration, Red.



FRINGE ANGLE = 4.80 mrad (0.275 deg.)

Figure 14. Fringe Angle Calibration, Blue.

Rounds 17460 and 17462 - The purpose of these rounds was to evaluate the use of circular dither with two laser lines to measure all three angles of a non-spinning projectile. The reflector assemblies were calibrated in the precision 2-axis mount prior to firing the rounds. The hologram configuration was the orthogonal nested holographic grating as described in the preceding section. The hologram diffraction angle was one degree.

Fringe data was obtained for both of these rounds, and the signals are quite clean. Unfortunately, the rounds were very dynamic. The fringe rate is too high for processing with the algorithm that was developed on this program. The date reduction algorithm is designed for the case where the fringe rate is small compared to the dither rate. Figure 15 shows the output of the data reduction algorithm for these rounds. Figure 16 is the range data for round 17460.

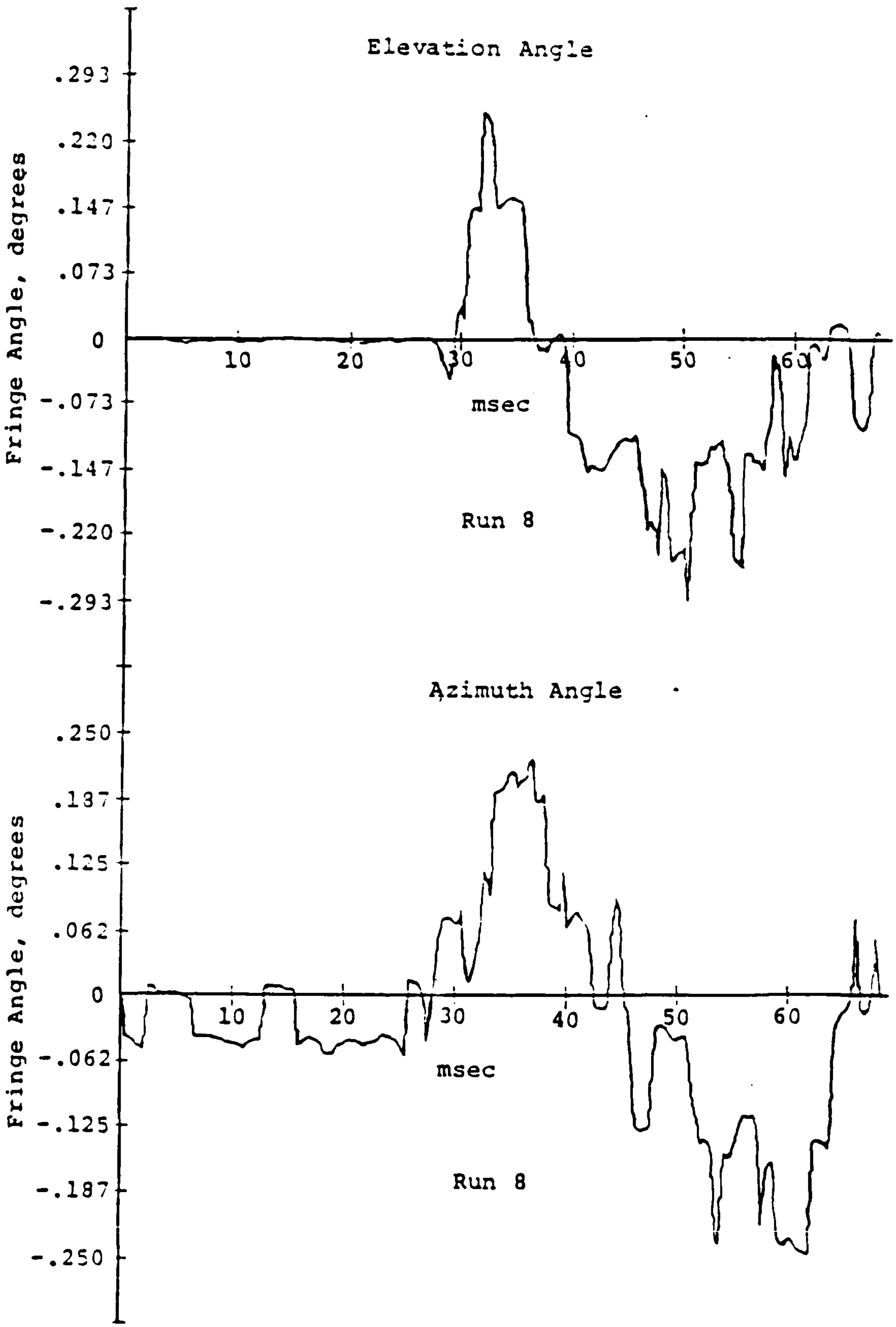


Figure 15. Computer Output, Round 17460.

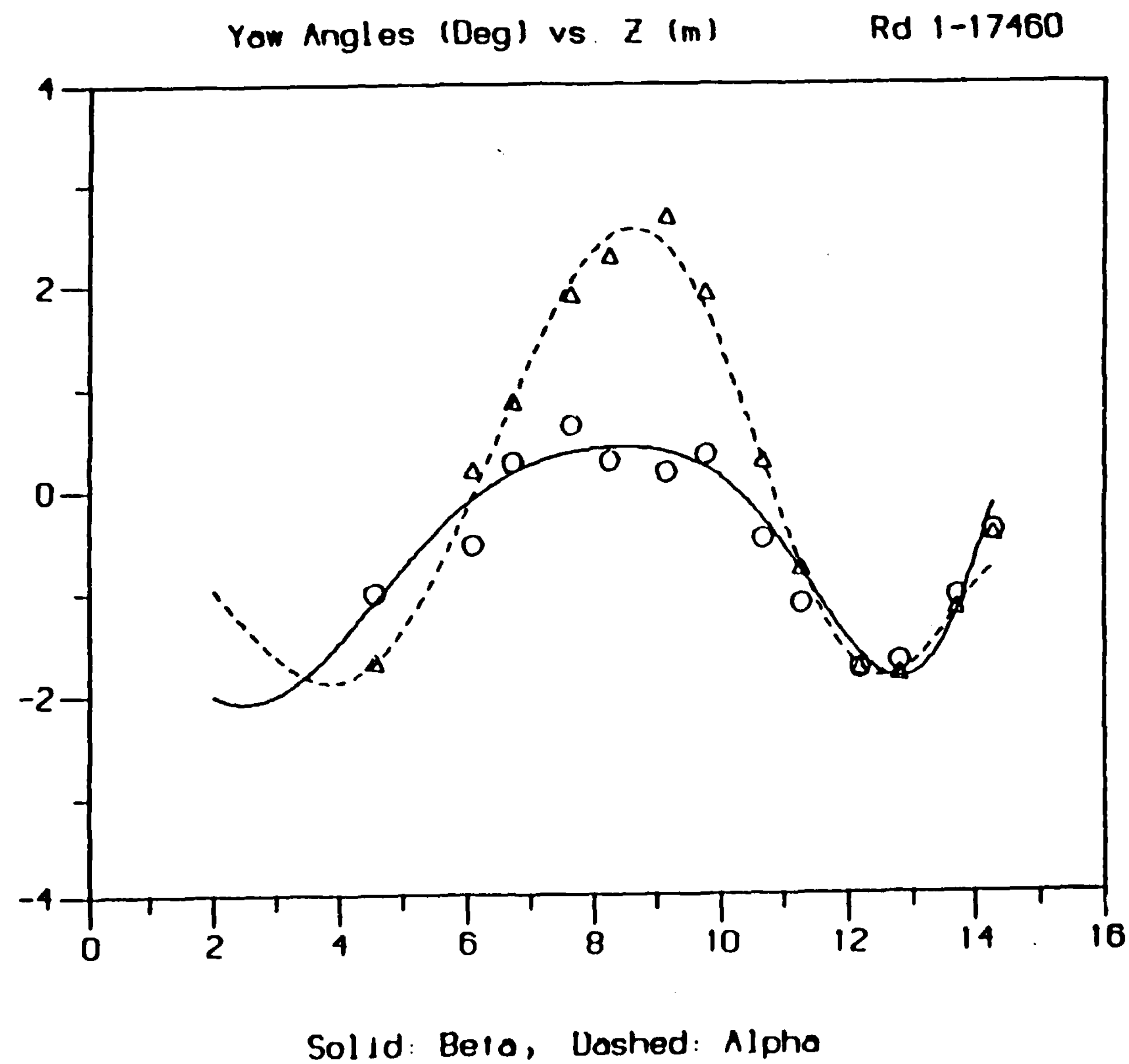


Figure 16. Yaw Angles versus Z, Round 17460.

Round 17464 - In-Bore. The optical unit was in the loading room. The laser beam passed through a 50 mm hole in the blast room wall and was directed by a pair of mirrors into the muzzle. The projectile base was fitted with a rubber seal in an attempt to prevent the passage of combustion gases. The seal failed, and no data was obtained from this round due to obscuration of the optical beam by leakage of hot combustion gases.

Rounds 17466 and 17467 - Muzzle Angle and Displacement. This setup is similar to the in-bore setup, except that the second folding mirror directed the laser beams to a reflector assembly mounted on a collar attached to the muzzle. In addition, the Boeing Dynamic Displacement Measurement System (DDMS) was used to measure the horizontal displacement of the muzzle.

Figures 17 and 18 are reduced angle data for these rounds. The blue laser measures the azimuth angle and the red laser measures the elevation angle.

DDMS counter output versus sample number is shown in Figure 19. Positive numbers correspond to displacement toward the right side of the range, looking down-range. The sample rate is 36 kHz.

The data for run 14, round 17466, indicates no motion for the first 5.6 milliseconds (200 samples), then a linear displacement of .280 millimeters in the following 2.5 milliseconds. The DDMS record then becomes flat, indicating that hot muzzle gases have passed through the beam. The hot gas destroys the lateral coherence of the signal beam, so the fringe count stops. The hot gas also affects the angle measurement system.

The displacement data can be used to estimate angular motion. Assume that the gun-tube bending follows a circular arc, then the angular change at the end of the tube is equal to the displacement divided by one-half the tube length. This results in an angle of 0.56 milliradian (0.032 degrees) for round 17466.

Proximity probes (used by BRL personnel following the above series of tests) registered a peak pointing angle of roughly 0.1 degree in the horizontal direction and a somewhat larger angle in the vertical direction.

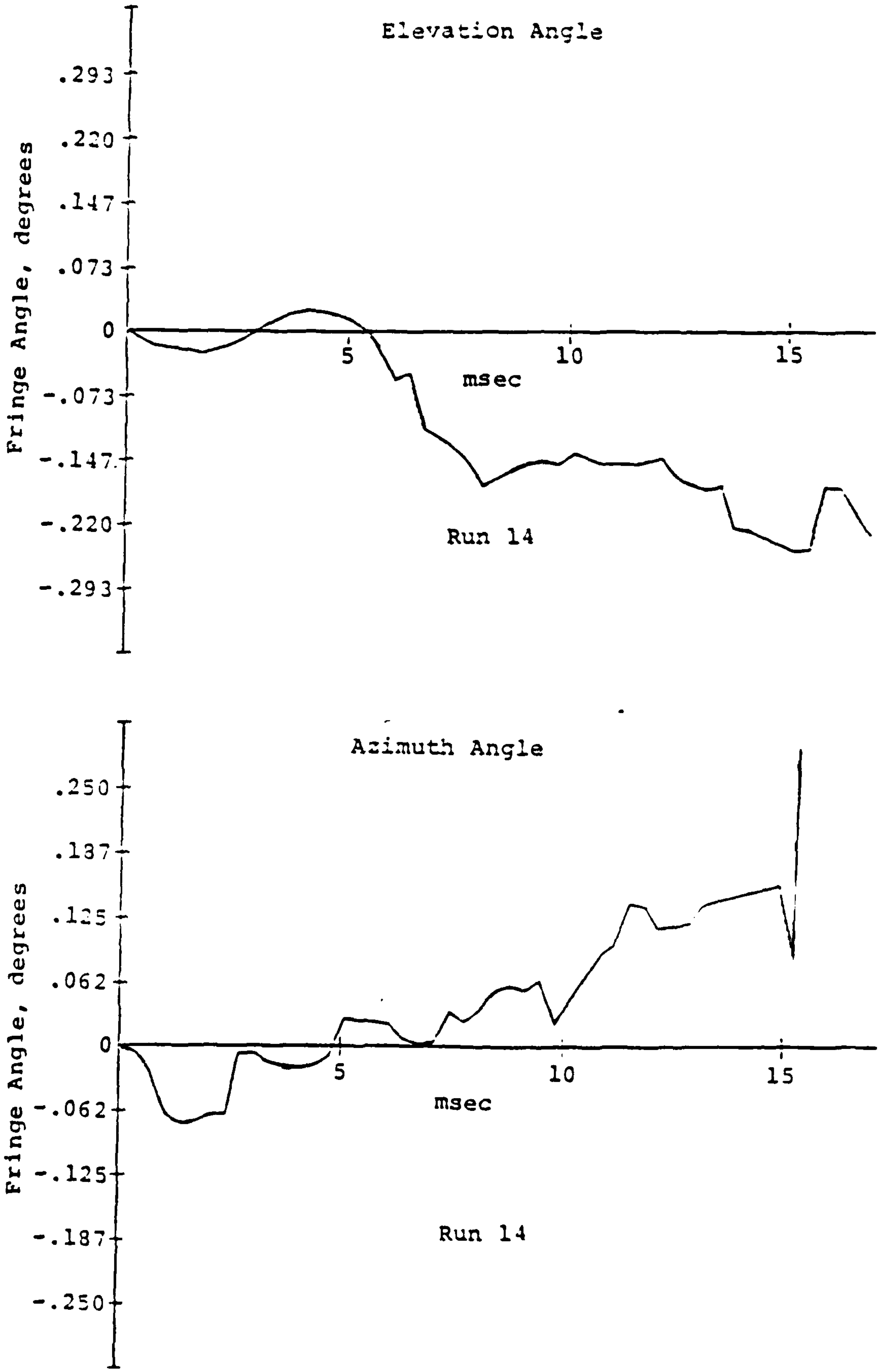


Figure 17. Muzzle Angle, Round 17466.

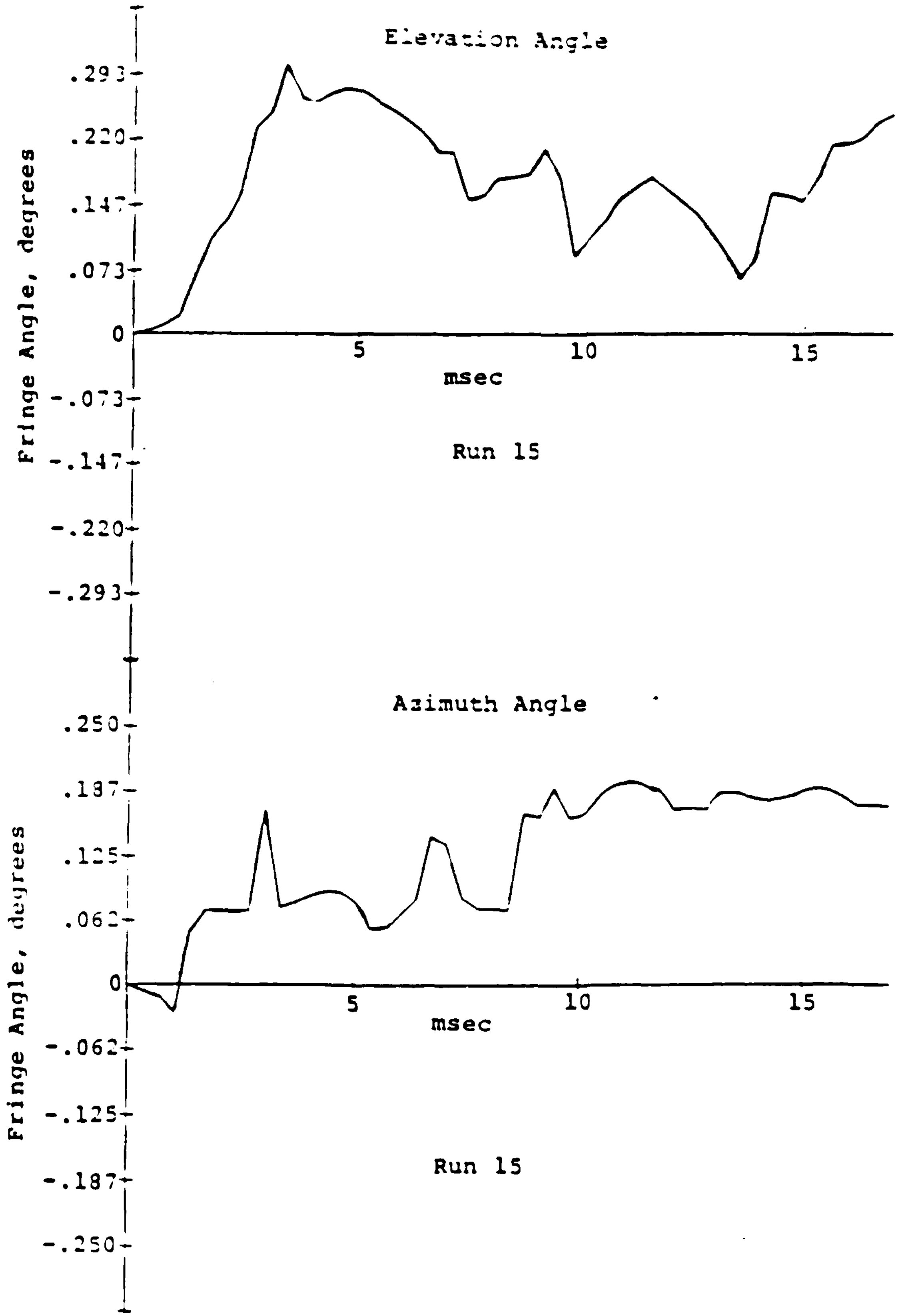


Figure 18. Muzzle Angle, Round 17467.

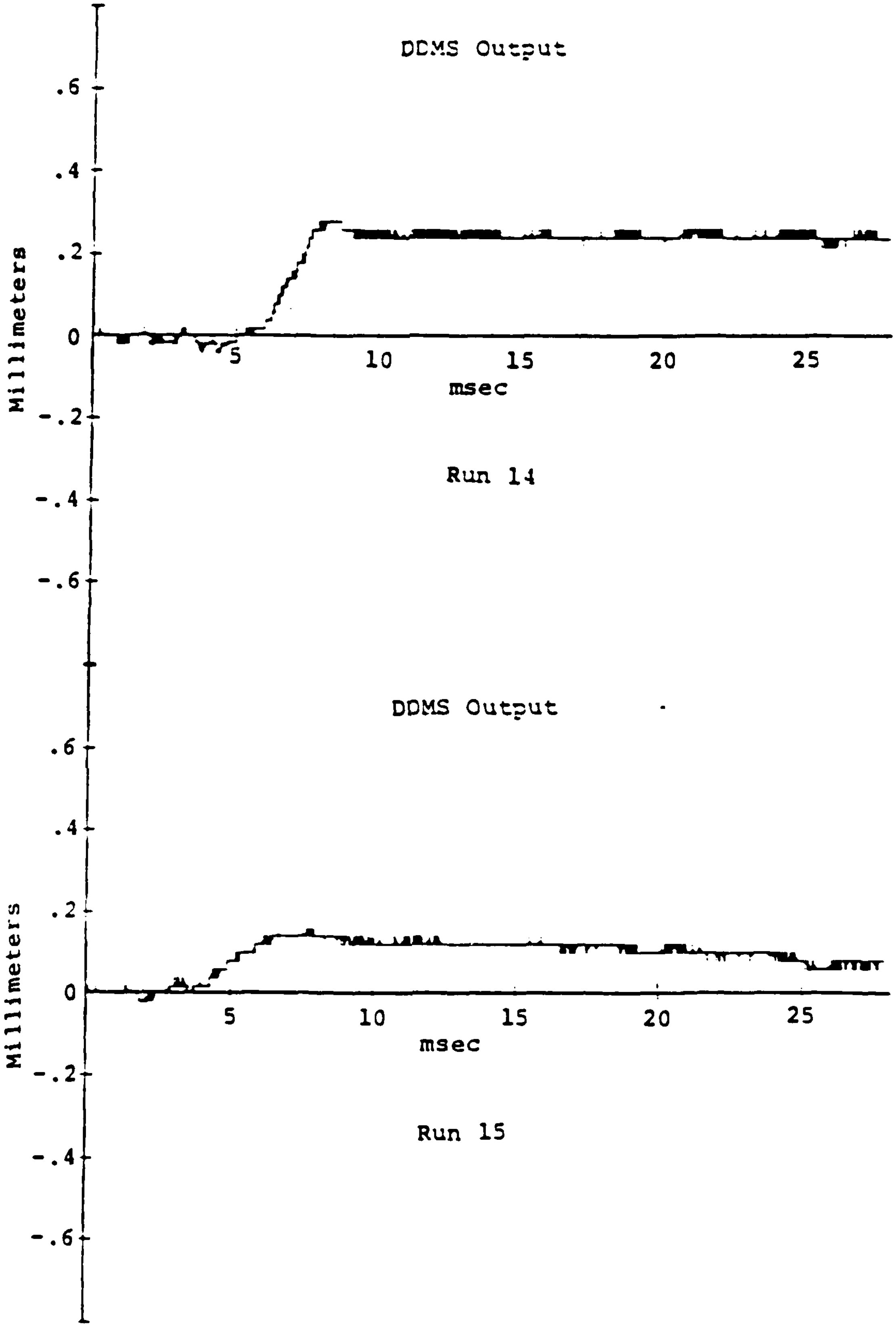


Figure 19. Muzzle Displacement, Round 17466 and 17467.

ANALYTIC MODEL

The equations relating the projectile angular motion with the output current from the photodetector will be developed in this section. The relationships for the general case (a spinning, yawing projectile observed by an optical system employing circular dither) are first derived. The simplifications that result when using a fixed laser beam or non-spinning projectile are then discussed.

A right-handed coordinate system is used in the analysis, with the X axis horizontal, the Y axis vertical and the Z axis along the range centerline. The optical centerline also coincides with the Z axis. The projectile undergoes pitching and yawing motions as a function of time, so the orientation of a projectile based coordinate system (x,y,z) may be specified by the direction cosines ($\cos\alpha_p$, $\cos\beta_p$) as shown in Figure 20-a.

The intensity of light reflected by the holographic grating/retroreflector combination placed at the nose of the projectile is a function of the angular orientation of the input laser beam relative to an axis normal to the hologram (Reference 1). It is therefore convenient to express the orientation of the body in terms of the angular coordinates

$$(u_p, v_p) = (\cos\alpha_p, \cos\beta_p)$$

where u_p and v_p may be thought of as the pitch and yaw of the projectile. The angles are chosen so that u_p is oriented perpendicular to the hologram grating lines (i.e. parallel to the direction in which light is diffracted). If the input angle is small, the reflection coefficient, $R[u_p(t)]$ is approximately a periodic function of the input angle as shown in Figure 20-b.

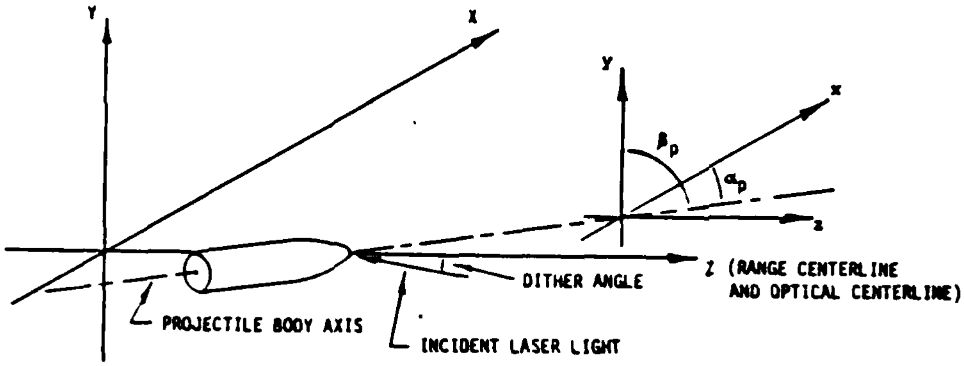
As part of the optical system, circular dither will be imparted to the laser light. Thus at any instant of time the angle between a ray representing the portion of the laser beam striking the retroreflector and the coordinate axes can be defined by the angular coordinates

$$(u_l, v_l) = (\cos\alpha_l, \cos\alpha_l)$$

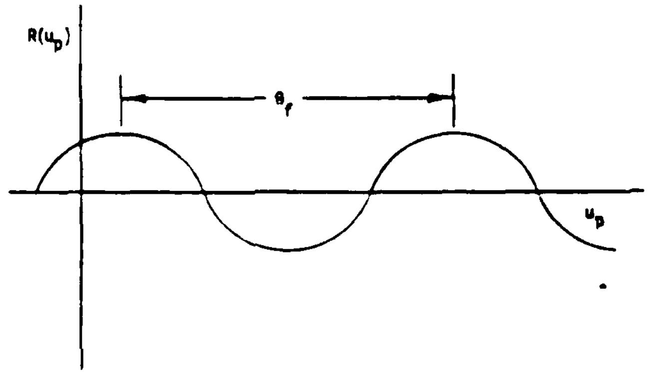
where α_l and β_l are the angles between the incident light and the X and Y axes respectively. Employing a trigonometric identity, the angle between the laser beam (or the body axis) and the Z axis may be expressed as

$$\gamma = \cos^{-1}(1 - \cos^2\alpha - \cos^2\beta)^{1/2}$$

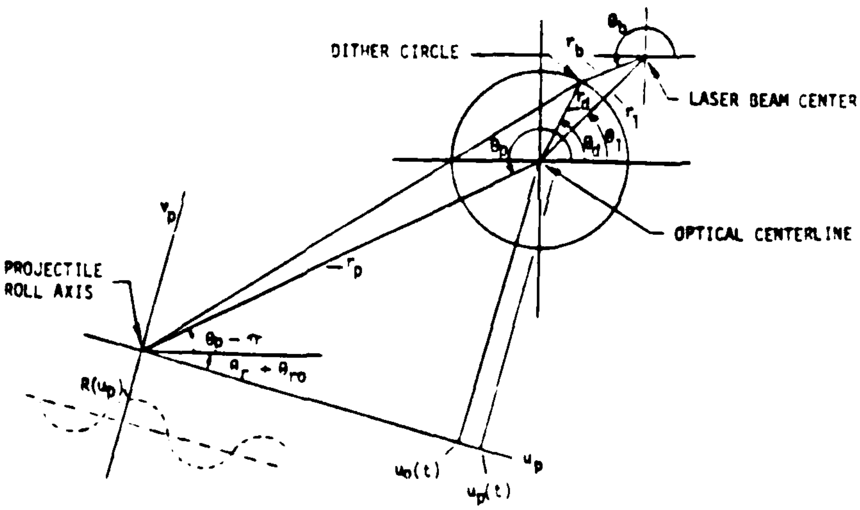
Figure 20-c illustrates the optical and projectile coordinate systems. The axes u_l and v_l are centered on the



a) Projectile Geometry



b) Reflector Reflection Coefficient versus Angle



c) Angular Geometry of Projectile and Laser Beam

Figure 20. Analytic Model Geometry.

optical centerline with u_1 horizontal. The body fixed projectile axes, u_p and v_p, rotate as the projectile rolls. The circle represents a circular dither of the laser beam. The polar coordinates of the center of the laser beam are (r_1, θ_1).

The circular dither can be resolved into time varying components in the projectile coordinate system

$$u_p(t) = r_d \cos(w_d t - w_r t + \theta_{do} - \theta_{ro}) + u_o(t)$$

$$v_p(t) = r_d \sin(w_d t - w_r t + \theta_{do} - \theta_{ro}) + u_o(t)$$

where r_d = angular radius of the circular dither
w_d = dither angular frequency
w_r = roll angular frequency
θ_{do} = initial dither angle
θ_{ro} = initial roll angle
$u_o(t), v_o(t)$ = position of optical axis in projectile coordinates.

The component of the dither in the u_p direction (perpendicular to the holographic grating lines) produces a modulated output, while the component in the v_p direction (parallel to the grating lines) does not.

The detector current is the product of two time varying functions. Since the intensity of the laser is not spatially uniform, as the beam is swept across the reflector (due either to the dither or the motion of the projectile) the light entering the retroreflector is amplitude modulated. The reflector further modulates the beam because the reflection coefficient, $R[u_p(t)]$, varies with the angle of incidence.

If it is initially assumed that the laser beam profile is not a function of z, then the intensity may be represented by

$$I(t) = (r_b, \theta_b)$$

where $r_b = (r_d{}^2 + r_1{}^2 - 2 r_d r_1 \cos(\theta_{do} + w_d t - \theta_1))^{1/2}$

$$\theta_b = \cos^{-1}[(r_d{}^2 - r_b{}^2 - r_1{}^2)/2 r_b r_1]$$

The circular dither is actually a conical scan with a fixed point at a distance z from the initial projectile position. The linear displacement of the beam with respect to the retroreflector is a function of $z - z_o$ (when $z = z_o$ there is no translation of the beam). The z axis dependence can be placed into the expression for I(t) by replacing r_1 with $r_1(t)$, where

$$r_1(t) = r_1(0) \cdot (z_o - z(t))/z_o$$

The photodector current is therefore

$$i(t) = \rho\Gamma I(t)\, R[u_p(t)]$$

where ρ = detector responsivity (amp/watt)
Γ = optical efficiency
I = laser beam intensity

Two special cases will be considered, both assuming that the laser beam is uniform, so that I(t) is constant.

(1) The retroreflector reflection coefficient is a pure sinusoid with period θ_f.

(2) The reflection coefficient is periodic, but has higher order components.

Case 1: $R[u_p(t)] = a + b \sin(2\pi u_p(t)/\theta_f - c)$

where a = average value
b = amplitude
θ_f = angle between fringes
c = phase at t=0

$$u_p(t) = r_d \cos(w_d t - w_r t + \theta_{do} - \theta_{ro}) + u_o(t)$$

Let $d = \rho\Gamma I$, $k = 2\pi/\theta_f$ and $w = w_d t - w_r t + \theta_{do} - \theta_{ro}$ then the detector current is

$$i(t) = ad + bd \sin[kr_d \cos w + ku_o(t) - c]$$

Express the sine term as a sum to get

$$i(t) = ad + bd \sin(kr_d \cos w) \cos(ku_o(t) - c)$$

$$+ bd \cos(kr_d \cos w) \sin(ku_o(t) - c)$$

We can then expand the terms with sinusoidal argument using the Bessel function identities

$$\sin(z\cos\theta) = 2J_1(z)\cos\theta - 2J_3(z)\cos 3\theta + \ldots$$

$$\cos(z\cos\theta) = J_0(z) - 2J_2(z)\cos 2\theta + 2J_4(z)\cos 4\theta - \ldots$$

The first few terms are

$$i(t) = ad + bd\, J_0(kr_d) \sin(ku_o(t) - c)$$

$$+ 2bd\, J_1(kr_d) \cos w \cos(ku_o(t) - c)$$

$$- 2bd\, J_2(kr_d) \cos 2w \sin(ku_o(t) - c)$$

$$2bd\, J_3(kr_d) \cos 3w \cos(ku_o(t) - c) +$$

These harmonic components can be separated by filtering, then bidirectional changes in $u_o(t)$ can be determined by tracking the coefficients of cos $[ku_o(t)]$ and sin $[ku_o(t)]$ for a pair of even and odd harmonics. Note that the harmonic frequencies are multiples of the difference between the dither and roll frequencies. If the dither is high compared to the roll rate, roll produces a slow change in the phase of the dither.

Case 2: R(u) is periodic but not a sinusoid.

The projectile reflector must be calibrated before firing. During calibration, R(u) is measured over at least one period of θ_f. If the dither is on, the amplitudes of two adjacent harmonics are stored in a look-up table of harmonic amplitudes versus angle. If the dither is off, the table entries can be calculated as follows:

Write R(u) as a Fourier series

$$R(u) = a_0/2 + a_1 \cos(ku) + a_2 \cos(2ku) + \ldots$$

$$+ b_1 \sin(ku) + b_2 \sin(2ku) + \ldots$$

Replace u with u + r_d cos(w), then expand each term using the Bessel function identities and collect like harmonics. The first few term of the expansion and rearrangement are:

$$R_o(u) = a_o/2 + \sum_{j=1}^{m} [a_j \cos(jku) + b_j \sin(jku)]\, J_o(jkr_d)$$

$$R_1(u) = 2 \cos w \sum_{j=1}^{m} [a_j \sin(jku) - b_j \cos(jku)]\, J_1(jkr_d)$$

$$R_2(u) = 2 \cos 2w \sum_{j=1}^{m} [a_j \cos(jku) + b_j \sin(jku)]\, J_2(jkr_d)$$

$$R_3(u) = 2 \cos 3w \sum_{j=1}^{m} [a_j \sin(jku) - b_j \sin(jku)]\, J_3(jkr_d)$$

These are the harmonic amplitudes for the look-up table. The table is used to reduce the data after the round is fired.

The data is reduced in increments of the dither minus roll period. For each increment, harmonic component amplitudes can be found with the digital filtering routine in the data reduction algorithm. The look-up table is used to find the fractional angle u, where $u \leq \theta_f$. The total angle is incremented or decremented by θ_f each time u moves through the table.

PRELIMINARY DESIGN

This section contains preliminary design information for a three angle measurement system. The design addresses the limitations of the breadboard system tested at BRL, and defines the areas which require further development before a final design can be implemented.

The major limitation of the breadboard system was the dither rate. An available galvanometer deflection system was used to generate a conical scan at 3 KHz. However, in many cases the fringe rate was comparable to the dither rate. The dither rate must be much higher than the fringe rate, otherwise, the desired effect of the dither modulation is destroyed and angle information cannot be recovered. Spin stabilized rounds with fringe rates of 30 KHz have been observed in our test program. A dither rate of the order of 1 MHz would be appropriate. Oscillating mirrors (galvanometer type of resonant scanners) have a capability up to 20 KHz. Polygonal mirrors on turbine motors can generate higher scan rates, but produce linear rather than conical scans. The mechanical limit (reference 3) for a polygonal mirror is:

$$w = \frac{1}{2\pi r_o}\sqrt{\frac{8UTS}{P(3+_n)}}$$

where r_o = Distance from center to edge
UTS = Ultimate tensile strength
n = Poisson's ratio of material
p = Volumetric density

Substituting the values for 6061 T6 aluminum, the mechanical limit for a 5 cm diameter scanner is about 10^4 revolutions/second. If the mirror had 20 facets, the scan rate would be 200 KHz. The practical limit, due to mirror deformation and safety, is well below the mechanical limit.

Acousto-optic beam deflectors (AOD) are an alternative method for generating a conical scan. Two-axis devices are available, so a circular dither is possible. The limit is set by the transit time of a sound wave across the aperture of the device. The transit time is the amount of time required to move the deflected beam from one position to another. Typical valves for commercial deflectors are of the order of 10 microseconds. In the breadboard system the return beam was sampled at 12 positions around the dither circle. If an AOD is used with 10 microsecond transit time to sequentially deflect the beam to 12 points on a circular arc, the maximum rate would be 8.51 KHz. This rate is also inadequate for a spinning projectile.

A solution to the high dither rate requirement is to use a circular array of diode laser beams, where the diode lasers are sequentially modulated to produce a rotating optical source. Very high dither frequencies are possible with this technique. (We are currently modulating a Mitsubishi model ML 3001 diode laser at a frequency of 1 GHz.) The wavelength of laser-diodes are temperature sensitive. Diode lasers are available with fiber optic pigtails, so the lasers can be mounted on a temperature controlled heat sink and the fibers led out to form a circular array in the focal plane of the collimating lens. Two color operation is accomplished by selecting lasers so the even and odd fibers radiate in different wavelength bands, such as 830±5nm and 850 ± 5nm.

Figure 21 shows two optical configurations. Both configurations show an off-axis paraboloid mirror for collimating the beam. The beam diameter would be of the order of 30 cm, so the refracting optics as used in this program become more expensive than off-axis optics. Furthermore, the Fresnel reflection from the center of a refractor is avoided with reflecting optics.

Figure 21a is a three-axis system for measurements of spinning projectiles, using techniques verified on this program. The concept shown in Figure 21b is a circular dither system using diode laser, as described above. The first technique is lower risk and cost, since all the techniques have been demonstrated in this program.

PHASE II PROGRAM

The major task in Phase II is the design and fabrication of a three-component angular measurement system. The results of the Phase I test program made a significant impact on the requirements for the Phase II system. The major requirement is for a much higher dither rate in order to follow the dynamics of some of the projectiles. Other requirements are increased laser beam diameter, improvements in the data reduction algorithms, and increased stability of the holograms in the humid environment at BRL. The Phase II tasks are listed below:

1) Design and fabricate a three-component angular measurement system. Two variations of the three-component system are possible.

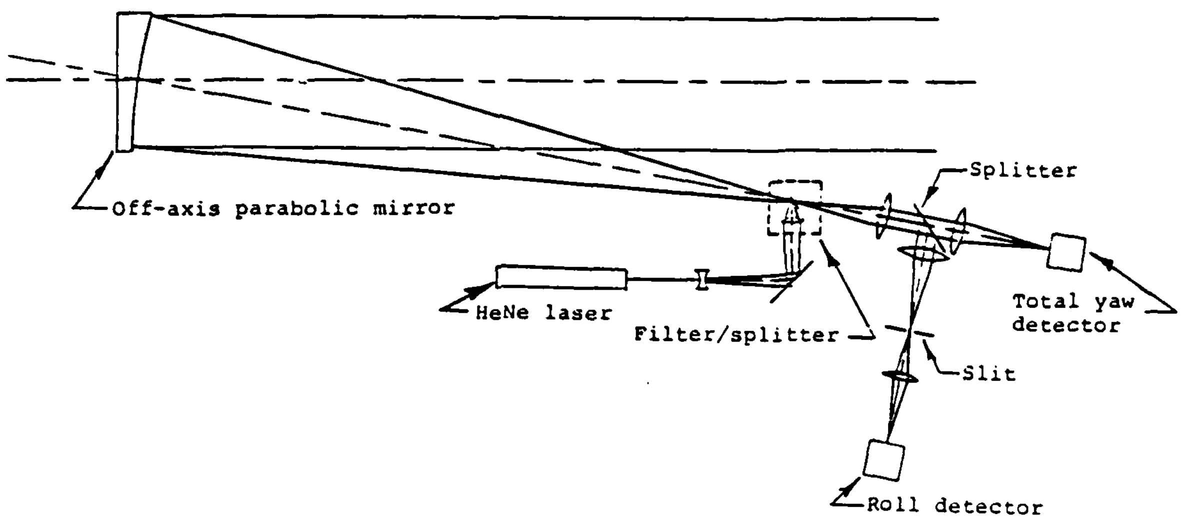
   a. Total yaw system for spinning projectiles. This technique was demonstrated on the prior contract, and improved to measure all three angles in the present contract.

   b. Three-component system with circular dither for both spinning and non-spinning projectiles. The technical difficulties are greater and the risks are higher for this system. At this time it appears that the only method for generating the required high dither rate is to use a circular array of optical fibers, each driven by a diode laser, where the relative phases of the diode lasers is adjusted to produce a conical scan. The dither generation technique should be thoroughly evaluated with a breadboard device prior to fabrication of the three-component system.

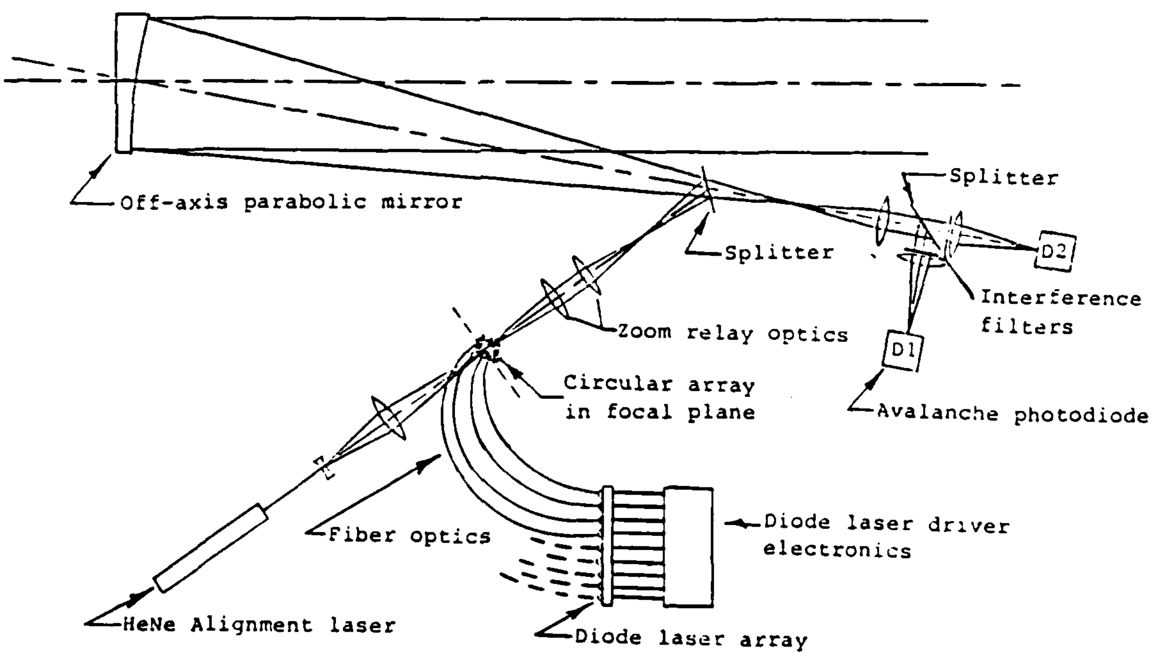
2) Data reduction algorithms

   a. No computer data reduction algorithm has been developed for 1a. Such a system would require the development of a suitable algorithm.

   b. The algorithm for 1b has partially been developed in Phase I. Additional development is required based on the results of Phase I and the analytic model developed in Phase I. One of the important problems to be addressed is the magnitude of error caused by the deviation of the reflector reflection coefficient from a sinusoid. The algorithm already developed is for the sinusoidal case, but the reflection coefficient is approximately sinusoidal only when the diffraction efficiency is low. In order to maximize the return power, it is necessary to operate with a reflection coefficient versus angle that departs significantly from a sinusoid.



a) Fixed Beam Optics



b) High Speed Circular Dither Optics

Figure 21. Laser Ballistic Sensor Configuration

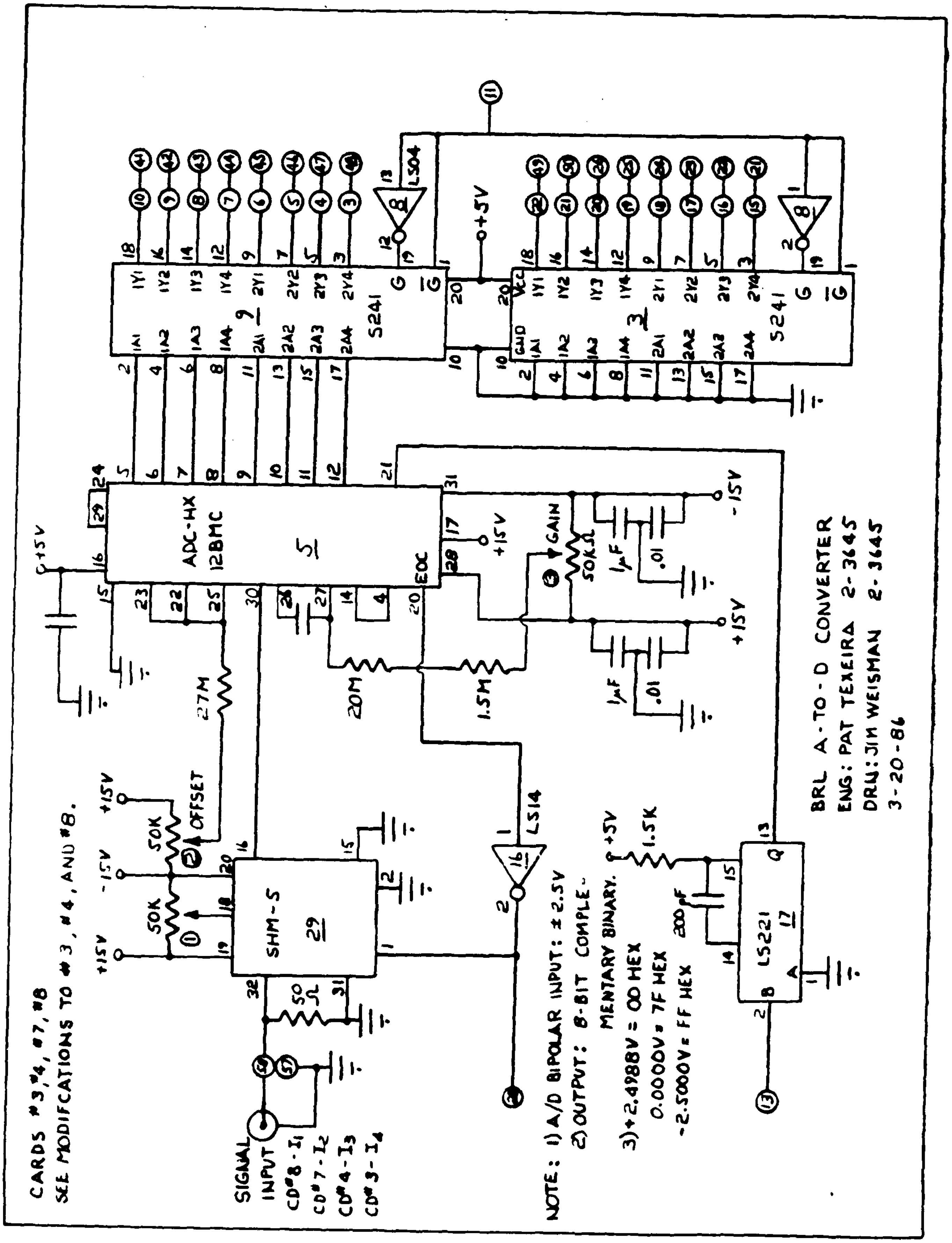
c. Algorithm development would be a joint Boeing and BRL task.

3) Investigate techniques to stabilize the holograms after fabrication. The diffraction efficiency of the holograms changed with time due to the change in relative humidity at BRL. Some of the holograms became cloudy and unusable.

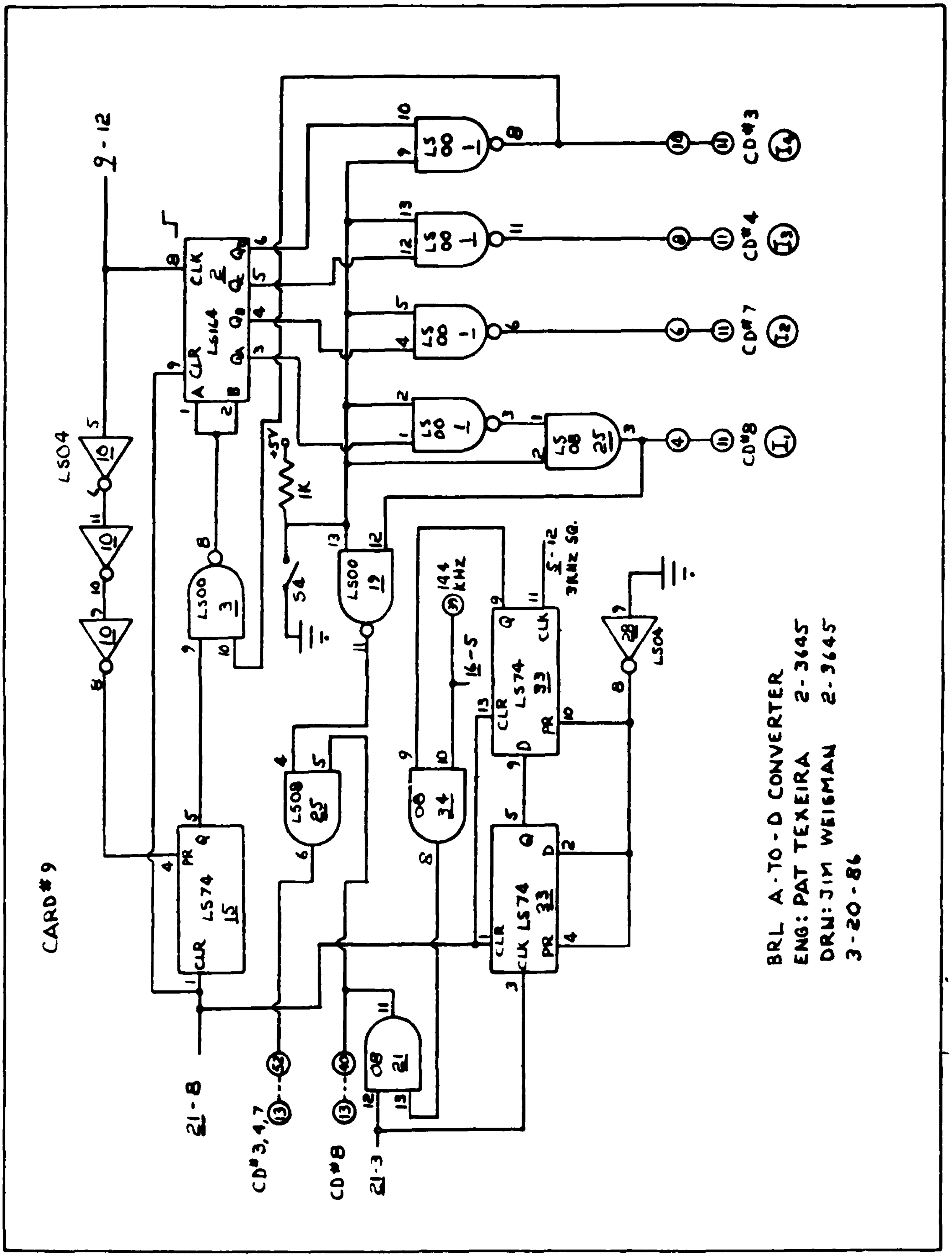
4) For the system of 1b, design and fabricate signal conditioning, timing, and computer interface circuitry for an acceptable dither frequency in the range of one megahertz.

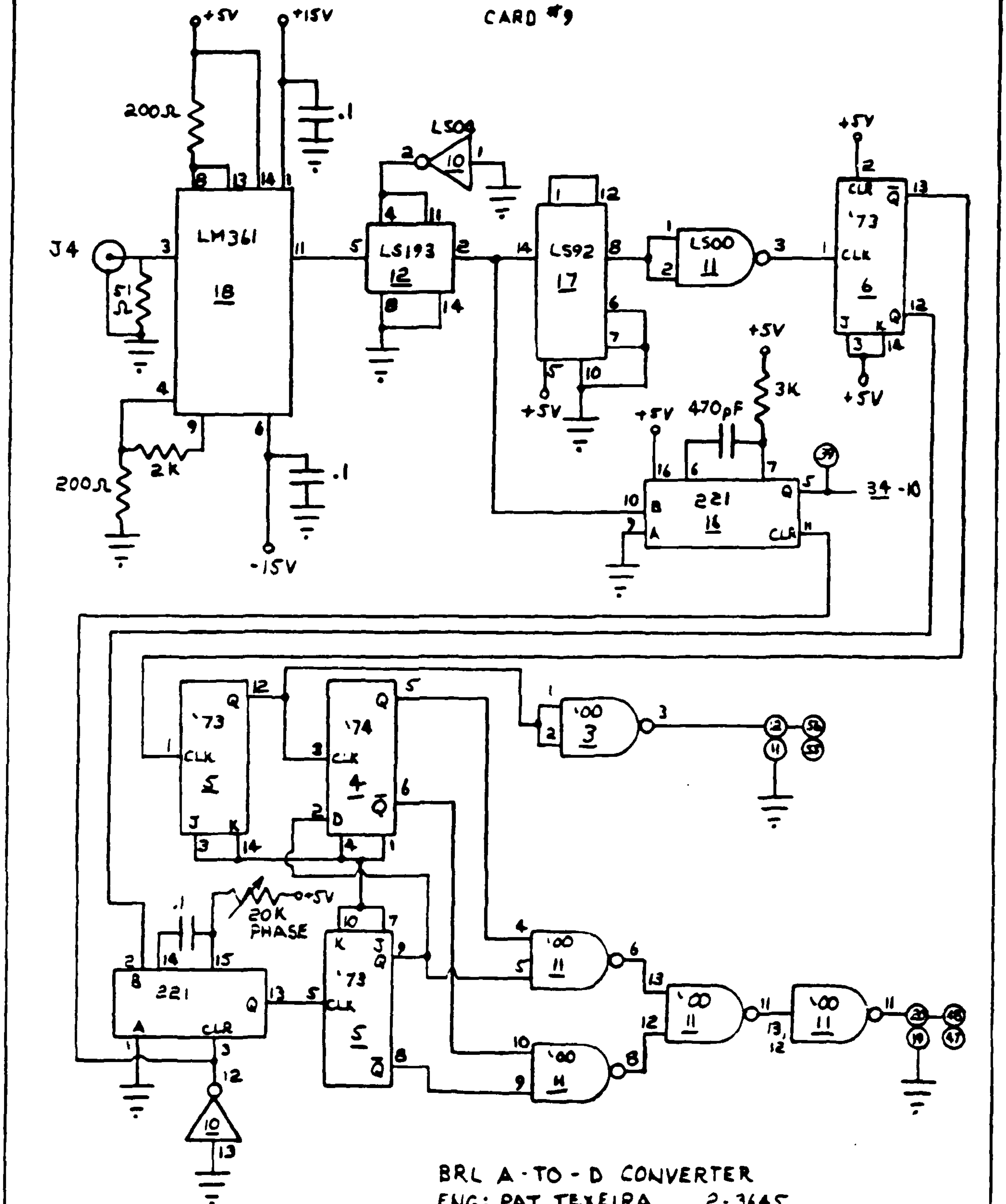
APPENDIX A

ELECTRONIC SCHEMATICS


BRL A-TO-D CONVERTER
ENG: PAT TEXEIRA 2-3645
DRW: JIM WEISMAN 2-3645
3-20-86
NOTE: 1) A/D BIPOLAR INPUT: ± 2.5V
2) OUTPUT: 8-BIT COMPLEMENTARY BINARY.
3) +2.4988V = 00 HEX
0.0000V = 7F HEX
-2.5000V = FF HEX
CARDS #3, #4, #7, #8
SEE MODIFCATIONS TO #3, #4, AND #8.
SIGNAL INPUT
CD#8 - I1
CD#7 - I2
CD#4 - I3
CD#3 - I4
ADC-HX 12BMC
SHM-5
S241
LS04
LS14
LS221
OFFSET
GAIN

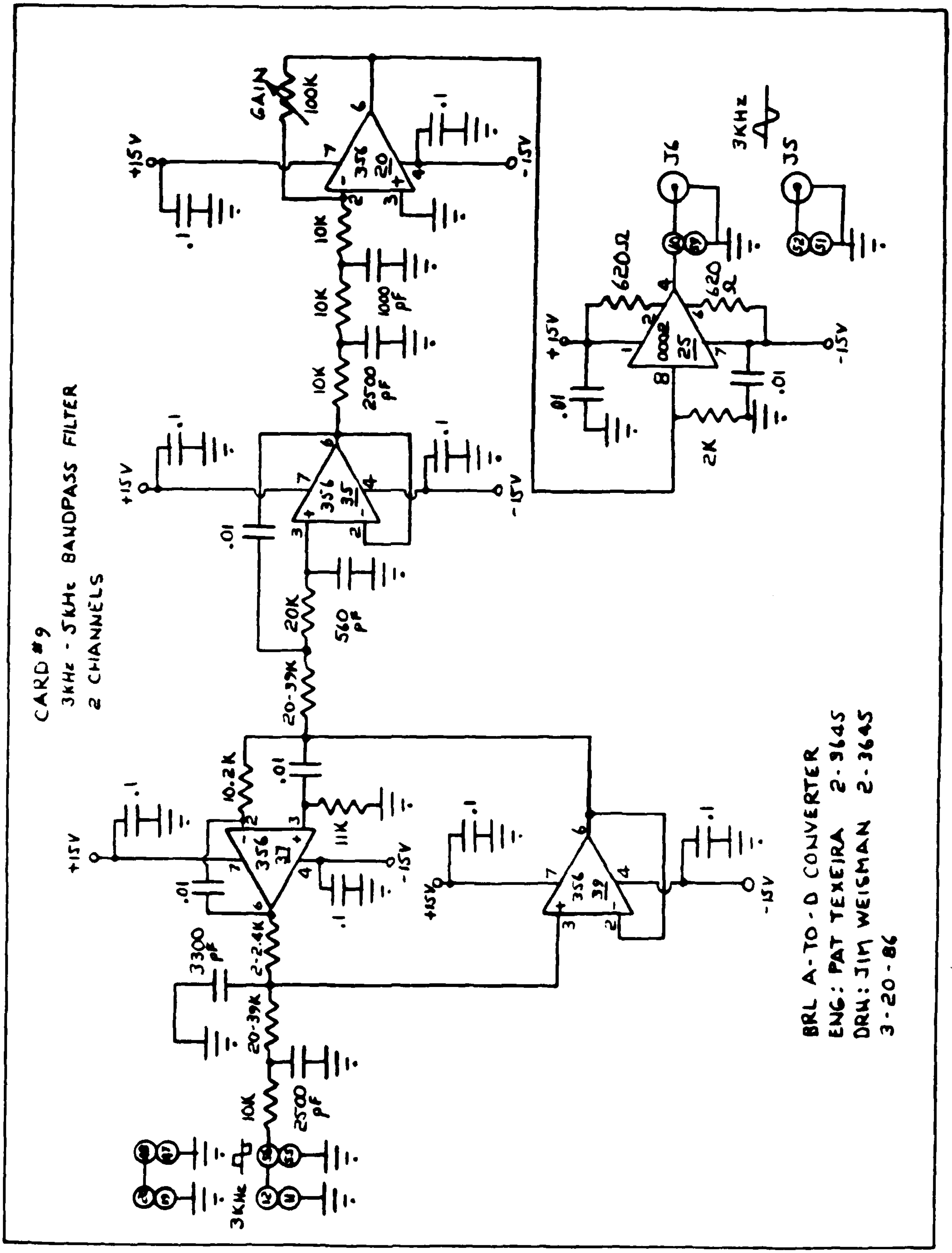
SHEET 1 OF 8

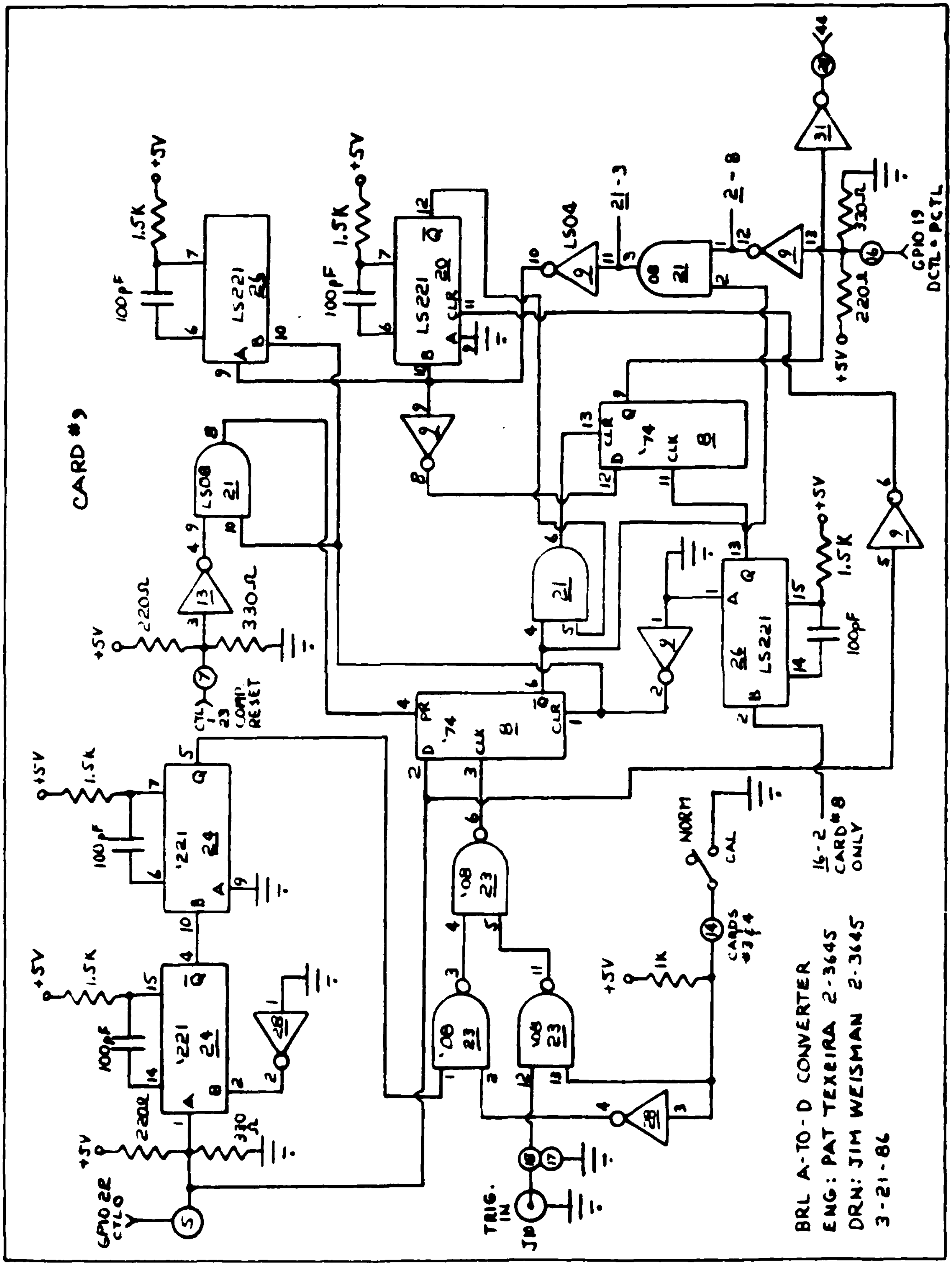

CARD#9
BRL A-TO-D CONVERTER
ENG: PAT TEXEIRA 2-3645
DRN: JIM WEISMAN 2-3645
3-20-86



BRL A-TO-D CONVERTER
ENG: PAT TEXEIRA 2-3645
DRN: JIM WEISMAN 2-3645
3-20-86

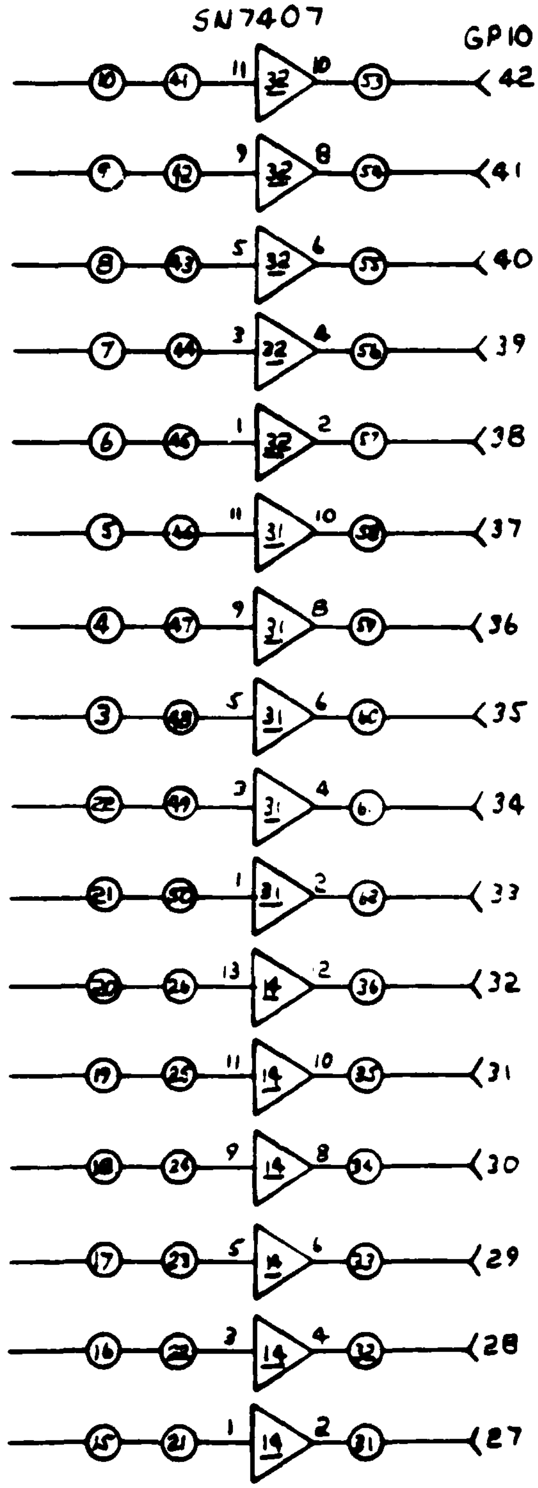
SHEET 3 OF 8


CARD #9
3KHz - 5KHz BANDPASS FILTER
2 CHANNELS
BRL A-TO-D CONVERTER
ENG: PAT TEXEIRA 2-3645
DRW: JIM WEISMAN 2-3645
3-20-86

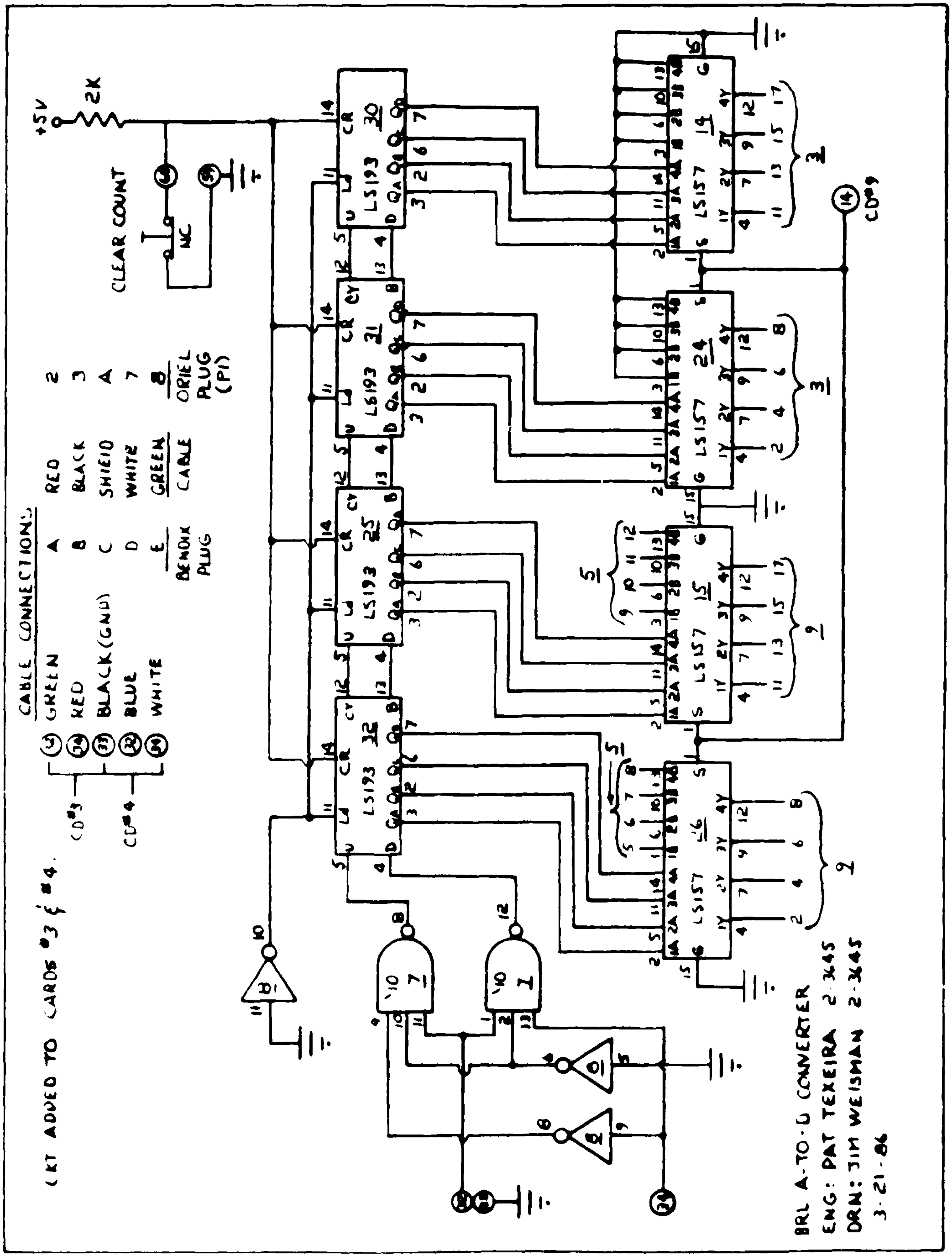

CARD #9
LS221
LS08
LS04
'74
'221
'08
TRIG. IN
J10
GPIO 22 CTLO
GPIO 19 DCTL • PCTL
COMP. RESET
NORM
CAL
16-2 CARD #8 ONLY
CARDS #3 & 4
BRL A-TO-D CONVERTER
ENG: PAT TEXEIRA 2-3645
DRN: JIM WEISMAN 2-3645
3-21-86

SHEET 5 OF 8

CARD #9

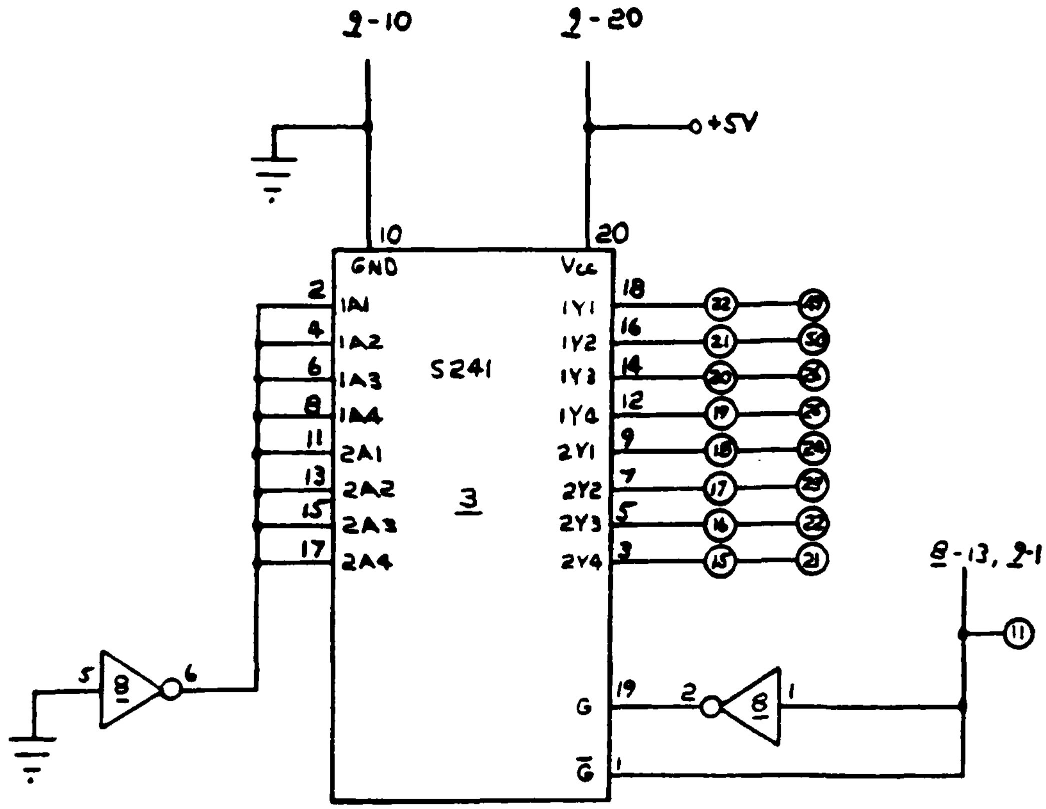


BRL A-TO-D CONVERTER
ENG: PAT TEXEIRA 2-3645
DRN: JIM WEISMAN 2-3645
3-21-86


CKT ADDED TO CARDS #3 & #4
CABLE CONNECTIONS
GREEN
RED
BLACK (GND)
BLUE
WHITE
CD#3
CD#4
A RED 2
B BLACK 3
C SHIELD A
D WHITE 7
E GREEN 8
BENDIX PLUG
CABLE
ORIEL PLUG (P1)
+5V
2K
CLEAR COUNT
NC
LS193
LS157
BRL A-TO-D CONVERTER
ENG: PAT TEXEIRA
DRN: JIM WEISMAN
3-21-86

SHEET 7 OF 8

MODIFICATION OF CARD #8



BRL A-TO-D CONVERTER
ENG: PAT TEXEIRA 2-3645
DRN: JIM WEISMAN 2-3645
3-21-86

APPENDIX B

COMPUTER PROGRAM

```
10     !BRL_6_28
11     !------------------------------------------
13     !PROGRAM FOR OBTAINING THE CALIBRATION CURVE FOR
14     !A GIVEN HOLOGRAM CORNER CUBE COMBINATION.
15     !--------------------------------------------
19 Comments:!This program uses the difference
20           !method for determining the amplitude
21           !for f2 & f1.
28           !The largest Num_samples is 32K.
31           !Graphing is included for 200 enve-
32           !lopes/graph. # of graphs depends on
33           !the number os Num_samples.
54           !Parameters of consideration: Ratios
55           !of f2/f1, degrees/count red(Dpcr),
56           !degrees/count blue(Dpcb)
57           !The doppler effect is included but
58           !not used(It was developed when this
59           !program was configured.).  It uses
60           !the parabolic fit to determine the
61           !location of the peak using the greater
62           !of the ampplitudes of f1 & f2.  The
63           !doppler correction is indepentent for
64           !the red & blue.
66           !For a/d interface- reset for counter
67           !and normal cal switch, up for cal.
68           PRINTER IS 1
70           PRINT CHR$(12)
71           PRINT TABXY(30,15),"CALIBRATION PROGRAM"
72           WAIT 3
73           PRINT TABXY(30,15),"                   "
74 Initialize:!
75     PRINTER IS 1
76     PRINT CHR$(12) !CLEAR SCREEN
77     ON ERROR GOTO Err_rout
78     OPTION BASE 0
79     GRAPHICS OFF
80     RAD
81     ON KEY 4 LABEL "GRAPH",15 GOSUB Disp_out
82     ENABLE
83     Gpio=12
84     Hpib=704
85     !CONSTANTS
86       Sf=36000 !Sample frequency
87       Gf=3000 !galvo frequency set by clock
88       K1=12  !samples at f1
89       K2=6   !samples at f2
90       K3=4   !samples at f3
91       !Signal generator frequency 576.000Khz
92     !VARIABLE LIST
93       !Num_samp : number of samples to take at 36kz rate
94       !Fb : filter bandwidth
95       !N : INT(Sf/fb)
96       !Nnn :INT (Num_samples/48)*12, used in DMA
97       !Br( ) : array, sampled data, red
98       !Bl( ) : array, sampled data, blue
99       !If1 : interpolation factor for f1
100      !If2 : interpolation factor for f2
101      !F1( ) : convolution multipling function for f1
102      !F2( ) : convolution multipling function for f2
103      !Start : starting point, determined by N
104      !Qr : starting sampled data point for next K1
```

```
105           !interval, including doppler correction, red.
106      !Qb : same as Qr except, blue
107      !Xx : Xx=1, loop for red:Xx=2 loop for blue
108      !B1( ) : Gimbal position for sample, red
109      !B2( ) : Gimbal position for sample, blue
110      !B1K1 : running sum of B1( ) in K1 interval
111      !B2K1 : running sum of B2( ) in K1 interval
112      !Filt_f1(J) : convolution elements in K1 interval, f1
113      !Filt_f2(J) : convolution elements in K1 interval, f2
114      !B1(P) : average of B1( ) in K1 interval
115      !B2(P) : average of B2( ) in k2 interval
116      !P : K1 interval of computation
117      !Ror : running sum of doppler correction, red
118      !Rob : running sum of doppler correction, blue
119      !Rotr(P) : running sum stored as a function of P
120      !Rotb(P) : running sum stored as a function of P
121      !Occr(P) : doppler correction for respective K1 interval, red
122      !Occb(P) : doppler correction for respective K1 interval, blue
123      !Qpsr : quadrant past, red
124      !Qpsb : quadrant past, blue
125      !Qptr : quadrant present, red
126      !Qptb : quadrant present, blue
127      !Qsr : running sum of quadrants, red
128      !Qsb : running sum of quadrants, blue
129      !Tar : total angle red, K1 interval
130      !Tab : total angle blue, K1 interval
131      !Ta_red(P) : total angle red, P K1 interval
132      !Ta_bl(P) : total angle blue. P K1 interval
133    !Whole quadrant update table
134    DIM Qt(5,4)
135    Qt(1,2)=1
136    Qt(1,4)=-1
137    Qt(2,1)=-1
138    Qt(2,3)=1
139    Qt(3,2)=-1
140    Qt(3,4)=1
141    Qt(4,1)=1
142    Qt(4,3)=-1
143    Qsr=10 !Quadrant sum red starts at 10
144    Qsb=10 !Quadrant sum blue starts at 10
145    ASSIGN @Gpio TO 12;WORD
146    !PRINT "      REGISTER STATUS BEFORE DMA"
147    !GOSUB Check_stat
148  Main:! Main program
149    PRINT CHR$(12)
150    GOSUB Num_samp       !# of samples to take
151       !GOSUB Test
152       !GOSUB File_data    ! Copy data from Buffer
153                          !to Disk File.
154       !GOSUB File_array
155    GOSUB Filt_bw_int  !Input filter bandwidth & interpolation factor
156    BEEP
157    INPUT "If calibration run, Type C.  else, Type S, for stored",Aa$
158    IF Aa$="C" OR Aa$="c" THEN
159       GOSUB Dma_transfer
160       GOSUB File_data
161       GOTO 174
162    END IF
163    IF Aa$="S" OR Aa$="s" THEN
164       DISP "INSERT DATA DISK - PRESS CONT TO CONTINUE'
165       PAUSE
```

```
166       CAT
167       GOSUB File_array
168       GOTO 174
169    END IF
170       BEEP
171       BEEP
172       BEEP
173       GOTO 157
174    GOSUB Mult_fun      !Generate multiplier
175                        !functions.
176    GOSUB Comp_angle    !Convolution, envelop detection, doppler correction,
177                        !& Arctan for red and blue
178    DISP
179    GOSUB Disp_out
180    GOTO 1
181 !++++++++++++++++++++++++++++++++++++++++
182 Num_samp: !Input the total number of samples
183           !to be taken. Maximum of 32K
184    BEEP
185    Num_samples=30000
186    GOTO 188
187    INPUT "TOTAL NUMBER OF SAMPLES TO BE TAKEN?",Num_samples
188    ALLOCATE REAL Ta_red(INT(Num_samples/K1)),Ta_bl(INT(Num_samples/K1)),Rot(I
NT(Num_samples/K1))
189    RETURN
190 Dma_transfer:!
191    DISP "                    COLLECTING DATA"
192    S=0
193    INTEGER Kk(0:47) BUFFER
194    ASSIGN @Buf TO BUFFER Kk(*)
195    !RESET DATA TRANSFER ELECTRONICS
196    CONTROL Gpio,2;2 !SET CTL0 & CTL1 TO 0
197    CONTROL Gpio,2;0 !SET CTL0 TO 1 & CTL1 TO 0
198    CONTROL Gpio,2;2 !SET CTL0 & CTL1 TO 1
199    !END RESET
200    CONTROL @Buf,4;0
201    CONTROL Gpio,0;2
202    CONTROL Gpio,3;0
203    !SET TRANSFER LOW
204    CONTROL Gpio,2;3 !SET CLT0 TO 0, XFER 0
205    !BEEP
206    TRANSFER @Gpio TO @Buf
207    FOR X=0 TO 47 STEP 4
208      Br(S)=Kk(X)-126
209      Bl(S)=Kk(X+1)+128
210      B1(S)=Kk(X+2)+1
211      B2(S)=Kk(X+3)+1
212    ! PRINT S,Br(S),Bl(S),B1(S),B2(S)
213      S=S+1
214    NEXT X
215    IF S=Nnn THEN
216      GOTO 220
217    ELSE
218      GOTO 196
219    END IF
220    CONTROL Gpio,2;2 !SET CLT0 & CLT1 TO 1
221    CONTROL Gpio,1;3
222    DISP
223    !PRINT "        REGISTER STATUS AFTER DMA"
224    !GOSUB Check_stat
225    BEEP
```

```
226   RETURN
246 Filt_bw_int:!Input filter bandwidth in hertz
247   BEEP
250   INPUT "WHAT IS THE DESIRED FILTER BANDWIDTH IN HERTZ?",Fb
251   N=INT(Sf/Fb)
253   Nnn=INT(Num_samples/48)*12
254   ALLOCATE INTEGER Br(0:Nnn),INTEGER B1(0:Nnn)
255   ALLOCATE INTEGER B1(0:Nnn),INTEGER B2(0:Nnn)
256   ALLOCATE INTEGER Rotr(0:Nnn),Rotb(0:Nnn),Qccr(0:Nnn),Qccb(0:Nnn)
257   PRINT CHR$(12)
258   BEEP
262   INPUT "Real samples f1=12, interpolation factor?",If1
263   BEEP
264   INPUT "Real samples f2=6, interpolation factor?",If2
265   BEEP
266   ALLOCATE REAL Filt_f1(1:K1*If1),Filt_f2(1:K1*If2)
267   RETURN
268 Test:! Generate data - needs to be modified for this
269        !program
272   BEEP
273   INPUT "What is the Envelop Peak Amplitude?",Epa
274   BEEP
275   DISP "                         GENERATING DATA"
276   Peak_value_data=0
277   Gal_cyc_frg=200
278   Ab=0
279   ALLOCATE INTEGER Mmm(0:Num_samples-1)
280   FOR X=0 TO Num_samples-1 STEP 4
281     Ac=Epa*SIN((PI*(+Ab))/(6*Gal_cyc_frg)+(2.7)*SIN(2*PI*Ab*Gf/Sf))
282     FOR Y=X TO X+3
283       Mmm(Y)=INT(Ac)+128
284              !PRINT Y,Mmm(Y)
285       OUTPUT @Buffer USING "#,B";Mmm(Y)
286     NEXT Y
287     Ab=Ab+1
288   NEXT X
289   DISP
290   GOSUB Check_stat
291   WAIT 5
292   RETURN
293 Mult_fun: !Generation of the multiplying function.
294            !Multiplying function will be (SIN(X)/(X))*COS(Y)
295            !PRINTER IS 705
296   !ALLOCATE REAL F1(0:(N*If1)),REAL F2(0:(N*If2))
297   DIM F1(0:2000),F2(0:2000)
298   RAD
299   BEEP
300    !Generate 1/2 multiplier function for F1
301   BEEP
302   DISP "Building multiplier function for F1"
303   F1(0)=1
304              !PRINT "F1(0)=";F1(0)
305   FOR P=1 TO N*If1
306     Aa=(PI*P)/(N*If1)
307     Bb=(Aa*2*Gf)/Fb
308              !PRINT "P=";P
309              !PRINT "N=";N*If1
310              !PRINT "(PI*P)/N=";Aa
311              !PRINT "(Aa*2*GF)/FB=";Bb
312     F1(P)=(SIN(Aa)/Aa)*COS(Bb)
313              !PRINT "F1(";P;")=";F1(P)
```

```
314   NEXT P
315   DISP "Building multiplier function for F2"
316    !Generate 1/2 of multiplier function for F2
317   F2(0)=1
318               !PRINT "F2(0)=";F2(0)
319   FOR P=1 TO N*If2
320     Aa=(PI*P)/(N*If2)
321     Bb=(Aa+4*Gf)/Fb
322               !PRINT "P=";P
323               !PRINT "N=";N
324               !PRINT "(PI*P)/N=";Aa
325               !PRINT "(Aa*4*GF)/FB=";Bb
326     F2(P)=(SIN(Aa)/Aa)*COS(Bb)
327               !PRINT "F2(";P;")=";F2(P)
328   NEXT P
329   RETURN
330 !
331 !.........................................
332 !Convolution and envelop detection
333 !at K1 intervals for f1 and f2.
334 !.........................................
335 !
336 Comp_angle:!Filter, envelop detection,
337                 !doppler correction and
338                 !arctan for red & blue
340   RAD
341   Tot_angle_peak=0
342   P=0       !Initializaton of array for the out-
343             !put angle for red and blue lasers.
344      !Determine first data point to start con-
345      !volution considering the value of N and
346      !the need of a + slope for f1 for synchr-
347      !onization.
348   Quotient=(N+1) DIV K1
349   Start=(Quotient+1)*12
351   BEEP
353   DISP "                          C R U N C H I N G   D A T A"
355   PRINT "Start=";Start
356   Qq=0  !Initialize graph index. Increment
357         !Qq for each 200 computations
361   Qr=Start+2-3
362   Qb=Qr
363   FOR Xx=1 TO 2 !1=red,2=blue
364     IF Xx=1 THEN
365       Q=Qr
366     ELSE
367       Q=Qb
368     END IF
369     B1k1=0
370     B2k1=0
373 !..........................................
374 Cor_f1:!
375           !Convolution over K1 interval for
376           !F1
377 !..........................................
378     J=1
379     Peak_value_f1=0
380     FOR X=Q TO Q+K1-1
381       IF Xx=1 THEN B1k1=B1(X)+B1k1
382       IF Xx=2 THEN B2k1=B2(X)+B2k1
383       FOR C=0 TO If1-1
```

```
384          Sum_f1=0
385          IF Xx=1 THEN    !Xx=1,Red:Xx=2,Blue
386            FOR M=X TO X+N
387              Product_f1=Br(M+1)*F1((M-X)*If1-C+If1)+Br(2*X-M)*F1((M-X)*If1+C)
388              Sum_f1=Sum_f1+Product_f1
389             ! PRINT Q;TAB(10);X;TAB(20);C;TAB(30);M;TAB(40);J;TAB(45);((M-X)*
If1+C);
390             !  PRINT TAB(50);((M-X)*If1-C+If1);
391             !  PRINT TAB(60);(2*X-M-1)
392            NEXT M
393          ELSE
394            FOR M=X TO X+N
395              Product_f1=B1(M+1)*F1((M-X)*If1-C+If1)+B1(2*X-M)*F1((M-X)*If1+C)
396              Sum_f1=Sum_f1+Product_f1
397             !  PRINT Q;TAB(10);X;TAB(20);C;TAB(30);M;TAB(40);J;TAB(45);((M-X)
*If1+C);
398             !  PRINT TAB(50);((M-X)*If1-C+If1);
399             !  PRINT TAB(60);(2*X-M-1)
400            NEXT M
401          END IF
402          Filt_f1(J)=Sum_f1
403            !PRINTER IS 705
404            !PRINT "Filt_f1(";J;"=)";Filt_f1(J)
405            !PRINTER IS 1
406          IF ABS(Filt_f1(J))>Peak_value_f1 THEN
407            Peak_value_f1=ABS(Filt_f1(J))
408          END IF
409          J=J+1
410        NEXT C
411      NEXT X
412      IF Xx=1 THEN B1(P)=INT(B1k1/12)
413      IF Xx=2 THEN B2(P)=INT(B2k1/12)
419          !.....................................
420 Env_f1:!Envelop detection over K1
421          !interval for f1
422          !.....................................
423      Diff_plus_f1=0
424      Diff_minus_f1=0
425      FOR E=If1+1 TO 5*If1+1
426        Diff_f1=Filt_f1(E)-Filt_f1(E+INT(If1*K1/2))
427        IF Diff_f1>Diff_plus_f1 THEN
428          Diff_plus_f1=Diff_f1
429        END IF
430        IF Diff_f1<Diff_minus_f1 THEN
431          Diff_minus_f1=Diff_f1
432        END IF
433              !PRINT "e=";E,"Diff_f1=";Diff_f1
434              !PRINT "Diff_plus_f1=";Diff_plus_f1
435              !PRINT "Diff_minus_f1=";Diff_minus_f1
436      NEXT E
437         !Value of Envelop at P interval for f1
438      IF Diff_plus_f1>ABS(Diff_minus_f1) THEN
439        Envelop_f1=Diff_plus_f1
440      ELSE
441        Envelop_f1=Diff_minus_f1
442      END IF
478 !...............................................
479 Con_f2:!
480           !Convolution over K1 interval for f2
481 !...............................................
483      J=1
```

```
484      Peak_value_f2=0
485      FOR X=Q TO Q+K1-1
486        FOR C=0 TO If2-1
487          Sum_f2=0
488          IF Xx=1 THEN    !Xx=1,Red:Xx=2,Blue
489            FOR M=X TO X+N
490              Product_f2=Br(M+1)*F2((M-X)*If2-C+If2)+Br(2*X-M)*F2((M-X)*If2+C)
491              Sum_f2=Sum_f2+Product_f2
492          !   PRINT Q;TAB(10);X;TAB(20);C;TAB(30);M;TAB(40);J;TAB(45);((M-X)
*If2+C);
493          !   PRINT TAB(50);((M-X)*If2-C+If2);
494          !   PRINT TAB(60);(2*X-M-1)
495            NEXT M
496          ELSE
497            FOR M=X TO X+N
498              Product_f2=Bl(M+1)*F2((M-X)*If2-C+If2)+Bl(2*X-M)*F2((M-X)*If2+C)
499              Sum_f2=Sum_f2+Product_f2
500          !   PRINT Q;TAB(10);X;TAB(20);C;TAB(30);M;TAB(40);J;TAB(45);((M-X)
*If2+C);
501          !   PRINT TAB(50);((M-X)*If2-C+If2);
502          !   PRINT TAB(60);(2*X-M-1)
503            NEXT M
504          END IF
505          Filt_f2(J)=Sum_f2
506            !PRINTER IS 705
507            !PRINT "Filt_f2(";J;")";Filt_f2(J)
508            !PRINTER IS 1
509          IF ABS(Filt_f2(J))>Peak_value_f2 THEN
510            Peak_value_f2=ABS(Filt_f2(J))
511          END IF
512          J=J+1
513        NEXT C
514      NEXT X
520   !.....................................
521   Env_f2:!Envelop detection over fract-
522           !ional interval of K1 for f2
523           !using 1/2 cycle difference
525   !.....................................
526      Diff_plus_f2=0
527      Diff_minus_f2=0
528      FOR E=If2+1 TO 5*If2+1
529        Diff_f2=Filt_f2(E)-Filt_f2(E+3*If2)
530        IF Diff_f2>Diff_plus_f2 THEN
531          Diff_plus_f2=Diff_f2
532        END IF
533        IF Diff_f2<Diff_minus_f2 THEN
534          Diff_minus_f2=Diff_f2
535        END IF
536      NEXT E
540          !value of Envelop at P interval for f2
541      IF Diff_plus_f2>ABS(Diff_minus_f2) THEN
542        Envelop_f2=Diff_plus_f2
543      ELSE
544        Envelop_f2=Diff_minus_f2
545      END IF
546      !PRINT "Envelop_f2";Envelop_f2
547   !.........................................
548   !CORRECTION FOR THE DOPPLER EFFECT FOR RED
549   !                  AND BLUE
550   !.........................................
         IF ABS(Envelop_f1)>ABS(Envelop_f2) THEN
```

```
558       FOR E=If1+1 TO 5*If1+1
560         D2=Filt_f1(E+2)-Filt_f1(E+1)
561         D1=Filt_f1(E+1)-Filt_f1(E)
562        !PRINT "D2=";D2,"D1=";D1,"(D2-D1)=";D2-D1,"E=";E
563         IF D2=0 OR SGN(D1)+SGN(D2)=0 THEN
567           GOTO 571
568         END IF
569       NEXT E
571       Dsq=D2-D1
572       Ap=Filt_f1(E)
574       Bp=D1-Dsq/2
575       Cp=Dsq/2
577       Envelop_f11=(Ap-(Bp^2)/(4*Cp))
578       !PRINT "Envelop_f11=";Envelop_f11
580       Ee=E-Bp/(2*Cp)
581       !PRINTER IS 705
590       PRINT "Ee_f1=";Ee
591       PRINTER IS 1
593       Qc=0
594       IF Ee>4*If1+1 THEN Qc=-1
595       IF Ee<2*If1+1 THEN Qc=+1
598     ELSE
617       FOR E=If2+1 TO 5*If2+1
618         D2=Filt_f2(E+2)-Filt_f2(E+1)
619         D1=Filt_f2(E+1)-Filt_f2(E)
620         !PRINT "D2=";D2,"D1=";D1,"(D2-D1)=";D2-D1,"E=";E
621         IF D2=0 OR SGN(D1)+SGN(D2)=0 THEN
622           GOTO 626
623         END IF
625       NEXT E
626       Dsq=D2-D1
627       Ap=Filt_f2(E)
628       Bp=D1-Ds/2
629       Cp=Dsq/2
630       Envelop_f22=(Ap-(Bp^2)/(4*Cp))
631       !PRINT "Envelop_f22=";Envelop_f22
632       Ee=E-Bp/(2*Cp)
633       !PRINTER IS 705
635       PRINT "Ee_f2=";Ee
636       PRINTER IS 1
638       Qc=0
639       IF Ee>4*If2+1 THEN Qc=-1
640       IF Ee<2*If2+1 THEN Qc=+1
641     END IF
642     IF Xx=1 THEN
643       !PRINTER IS 705
645       Ror=Ror+Qc
646       PRINT "Ror=";Ror,
647       Rotr(P)=Ror
648       Qccr(P)=Qc
649       PRINT "Qc=";Qc
650       Qr=Qr+Qc+K1
651       PRINT "Qr=";Qr
652       PRINTER IS 1
654     ELSE
655       Rob=Rob+Qc
656       PRINT "Rob=";Rob
657       Rotb(P)=Rob
658       Qccb(P)=Qc
659       PRINT "Qc=";Qc,
660       Qb=Qb+Qc+K1
```

```
661      PRINT "Qb=";Qb
667    END IF
668    E_f1=Envelop_f1
669    E_f2=4*Envelop_f2
670    PRINT "Envelop_f2/Envelop_f1=";Envelop_f2/Envelop_f1
671      !.....................................
672 Arc_t:!Computation of the angle from the
673      !arctan(Envelop_f2/Envelop_F1) and
674      !counting of the whole quadrants
675      !.....................................
676      BEEP 500,.2
679    PRINTER IS 1
680    DEG
681    IF Xx=1 THEN ! Arc_t for Red laser
682      IF E_f1=0 THEN !Take care of divide by zero
683        IF Qpsr=1 OR Qpsr=3 THEN
684          Tar=(Qsr)*90+90
685          GOTO 716
686        ELSE
687          Tar=(Qsr)*90
688          GOTO 716
689        END IF
690      END IF
691      Ra=E_f2/E_f1
692      !Determine Quadrant & Total_angle(P)_
693      IF ABS(Ra)>=60 THEN
694        IF SGN(Ra)=1 THEN
695          Ra=60
696        ELSE
697          Ra=-60
698        END IF
699      END IF
700      IF SGN(Ra)=1 THEN !Plus Ratio
701        IF SGN(E_f1)=1 THEN ! Deno plus
702          Qptr=1
703        ELSE
704          Qptr=3
705        END IF
706        Tar=(Qt(Qpsr,Qptr)+Qsr)*90+ATN(Ra)-900
707      ELSE
708        IF SGN(E_f1)=1 THEN
709          Qptr=4
710        ELSE
711          Qptr=2
712        END IF
713        Tar=(Qt(Qpsr,Qptr)+Qsr)*90+90+ATN(Ra)-900
714      END IF
715      Qsr=Qt(Qpsr,Qptr)+Qsr
716      IF P>1 THEN Qpsr=Qptr
717      PRINTER IS 705
719      PRINT P,PROUND(Tar,-2),Qpsr,Qptr,B1(Q),B1(P)
720      PRINTER IS 1
722      Ta_red(P)=Tar
723      PRINTER IS 705
725      PRINT P,"Ta_red=";PROUND(Ta_red(P),-2),"E_F1=";E_f1,"E_F2=";E_f2
726      PRINTER IS 1
728    ELSE!Arc_t for blue laser
729      IF E_f1=0 THEN !Take care of divide by zero
730        IF Qpsb=1 OR Qpsb=3 THEN
731          Tab=(Qsb)*90+90
732          GOTO 763
```

```
733           ELSE
734             Tab=(Qsb)*90
735             GOTO 763
736           END IF
737         END IF
738         Ra=E_f2/E_f1
739         !Determine Quadrant & Total_angle(P)_
740         IF ABS(Ra)>=60 THEN
741           IF SGN(Ra)=1 THEN
742             Ra=60
743           ELSE
744             Ra=-60
745           END IF
746         END IF
747         IF SGN(Ra)=1 THEN !Plus Ratio
748           IF SGN(E_f1)=1 THEN ! Deno plus
749             Qptb=1
750           ELSE
751             Qptb=3
752           END IF
753           Tab=(Qt(Qpsb,Qptb)+Qsb)*90+ATN(Ra)-900
754         ELSE
755           IF SGN(E_f1)=1 THEN
756             Qptb=4
757           ELSE
758             Qptb=2
759           END IF
760           Tab=(Qt(Qpsb,Qptb)+Qsb)*90+90+ATN(Ra)-900
761         END IF
762         Qsb=Qt(Qpsb,Qptb)+Qsb
763         IF P>1 THEN Qpsb=Qptb
764         PRINTER IS 705
766         PRINT P,PROUND(Tab,-2),Qpsb,Qptb,B1(Q),B1(P)
767         Ta_bl(P)=Tab
768         PRINT P,"Ta_bl=";PROUND(Ta_bl(P),-2),"E_F1=";E_f1,"E_F2=";E_f2
769       END IF!For red or blue
770       PRINTER IS 1
771     NEXT Xx
772     RAD
773     PRINT
774       !This completes the angle computation
775       !for the red and blue for this K1 interval P
776     P=P+1
777       !Test to increment Qq or not
778     IF P=0 THEN
779       Qq=0
780     ELSE
781       Rmdr=P MOD 199      !P starts at 0
782       IF Rmdr=0 THEN Qq=Qq+1
783     END IF
784     !NEXT Q
785     IF Q>=Nnn-N-25-Start THEN RETURN
787     GOTO 363
788 Disp_out:!Graph data
789     Dpcr=.064           !Degrees/count gimbal red
790     Dpcb=.064           !Degrees/count gimbal blue
791     DUMP DEVICE IS 705
792     PRINTER IS 705
793     PEN 2
794     PRINT CHR$(12);     !Clear alpha & form feed
795     DISP
```

```
796   GINIT                    !Initialize
797   GRAPHICS ON              !Raster on
798   FOR Qqq=0 TO Qq !Graph index
799     FOR R=1 TO 2 !red=1, blue=2
800       PEN 2
801       WINDOW -25,200,-500,500!Set window
802       AXES 20,100
803       LORG 6
804       FOR I=0 TO 180 STEP 40
805         MOVE I,0
806         LABEL Qqq*200+I
807       NEXT I
808       !
809       LORG 8
810       FOR I=-400 TO 400 STEP 100
811         MOVE 0,I
812         LABEL I
813       NEXT I
814       !
815       LORG 5
816       MOVE 100,475
817       PEN 6
818       LABEL "ANGLE AS A FUNCTION OF ENVELOP SAMPLES"
819       MOVE 180,425
820       IF R=1 THEN
821       PEN 2
823       LABEL "RED"
824       MOVE 180, 400
825       LABEL Name$
827       PEN 6
828       END IF
829       IF R=2 THEN LABEL "BLUE"
830       MOVE 180,-400
831       LABEL Name$
833       PEN 2
834       MOVE -13,0
835       LORG 6
836       LABEL "Samp"
837       LORG 5
838       MOVE 100,-475
839       LABEL Title$;"ENVELOP SAMPLE RATE, 3KHZ"
840       PEN 0
841       MOVE 0,0
842       PEN 2
843       FOR X=0 TO 199 !graph data
844         IF R=1 THEN
845           Tb=Ta_red(Qqq*200+X+4)-Ta_red(4)
846         ELSE
847           Tb=Ta_bl(Qqq*200+X+4)-Ta_bl(4)
848         END IF
849         DRAW X,Tb
850       NEXT X
851       PEN 0
852       MOVE 0,0
853       PEN 6
854       FOR X=0 TO 199 !Graph gimbal
855         IF R=1 THEN
856           Bbb=B1(Qqq*200+X+4)*Dpcr-B1(4)*Dpcr
857         ELSE
858           Bbb=B2(Qqq*200+X+4)*Dpcb-B2(4)*Dpcb
859         END IF
```

```
860         DRAW X,-Bbb
861         NEXT X
862         PEN 0
863         PAUSE
864         !DUMP GRAPHICS
865         !PRINT CHR$(12)
866         GCLEAR
867       NEXT R
868     NEXT Qqq
869     ALPHA ON
870     PRINTER IS 1
871     DISP "STOP"
872     PAUSE
873     RETURN
874 Check_stat: !Status check on Buffer.
875     PRINT "             REGISTER STATUS @Buffer"
876     FOR X=1 TO 5
877       STATUS @Buffer,X;A
878       PRINT "REGISTER  ";X,A
879     NEXT X
880                   !DISP "PAUSE - PRESS CONTINUE TO CONTINUE"
881     BEEP
882                   !PAUSE
883     WAIT 5
884     PRINT CHR$(12)
885     RETURN
886 Err_rout:  !Routine for error recovery
887     BEEP
888     BEEP
889     BEEP
890     DISP ERRM$
891     PAUSE
892     GOSUB Disp_out
893     PAUSE
894       !
895 File_data: !Transfer of data from Buffer
896                 !to disk
897       !
898     BEEP
899     DISP "INSERT A FORMATTED DATA DISK!!!!!!! -- PRESS CONT TO CONT"
900     PAUSE
901       !Create a BDAT file for the data.
902     INPUT "NAME OF DATA FILE TO BE CREATED?",Name$
903     IF Name$="" THEN 902
904     BEEP
905     DISP "CREATING A DATA FILE"
906       !Record length is 1
907     CREATE BDAT Name$&":INTERNAL",8*Nnn+4,2
908       !Assign an I/O path
909     ASSIGN @File TO Name$&":INTERNAL"
910     GOSUB Check_stat_r
911     PRINT CHR$(12)
912     DISP "TRANSFERRING DATA FROM BUFFER TO FILE"
913     OUTPUT @File;Br(*),B1(*),B1(*),B2(*)
914     ASSIGN @File TO *
915     WAIT 5
916     DISP "TRANSFER COMPLETE"
917     WAIT 5
918     DISP
919     PRINT CHR$(12)
920     RETURN
```

```
921      !
922 File_array:  !Transfer from file to array
923      !
924   INPUT "NAME OF DATA FILE?",Name$
925   ASSIGN @File TO Name$&":INTERNAL"
926   BEEP
929   DISP "TRANSFERRING FROM DATA FILE TO AN ARRAY"
930   ENTER @File;Br(*),B1(*),B1(*),B2(*)
931   PRINT CHR$(12)
933   DISP "TRANSFER COMPLETE"
934   WAIT 3
938   !GOSUB Check_stat
939   !GOSUB Check_stat_r
940   !GOSUB Check_stat
941   DISP
942   RETURN
943 Check_stat_r: !Status check on File.
944   BEEP
945   PRINT "          REGISTER STATUS @File"
946   FOR R=1 TO 5
947     STATUS @File,R:A
948     PRINT "REGISTER  ";R,A
949   NEXT R
950             !DISP "PAUSE - PRESS CONTINUE TO CONTINUE"
951   BEEP
952             !PAUSE
953   WAIT 5
954   PRINT CHR$(12)
955   RETURN
956   END
```

Cross Reference

• Numeric Variables

A	877	878	947	948						
A_to_d_reset										
Aa	306	307	312	320	321	326				
Ab	278	281	287							
Ac	281	283								
Ap	572	577	627	630						
B1	210	255	381	412	719	766	856	913	930	
B1_peak										
B1k1	369	381	412							
B2	211	255	382	413	858	913	930			
B2_peak										
B2k1	370	382	413							
Bb	307	312	321	326						
Bb2										
Bbb	856	858	860							
Bbb2										
Bl	209	254	395	498	913	930				
Bp	574	577	580	628	630	632				
Br	208	254	387	490	913	930				
Buffer array										
Bw_label	383	387	395	410	486	490	498	513		
Check_stat										
Check_stat_r										
Comp_angle										
[illegible]	575	577	580	629	630	632				
[illegible]										
[illegible]										
[illegible]										
[illegible]										
[illegible]										
[illegible]	[illegible]	562	571	574	619	621	626	[illegible]		
[illegible]	560	563	571	618	621	626				
Diff t1	426	427	428	430	431					
Diff t2	529	530	531	533	534					
Diff minus t1	424	430	431	438	441					
Diff minus t2	527	533	534	541	544					
Diff plus t1	423	427	428	438	439					
Diff plus t2	526	530	531	541	542					
Disp con										
Disp data										
Disp data										
Disp data										
[illegible]										
Dma transfer										
[illegible]	[illegible]	858								
[illegible]	789	856								
[illegible]	628									
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
	[illegible]	[illegible]	436	[illegible]	[illegible]	[illegible]	558	560	[illegible]	[illegible]
	[illegible]	580	[illegible]	618	619	[illegible]	627	632		
[illegible]	662	682	691	701	708	725	729	738	748	[illegible]
	[illegible]									
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]					
[illegible]	580	590	594	595	632	[illegible]	[illegible]	641		
[illegible]	[illegible]	44?	[illegible]	[illegible]	[illegible]					
[illegible]	[illegible]									
[illegible]	[illegible]	644	[illegible]	[illegible]	670					

Envelop_f22	630									
Epa	273	281								
Err_rout										
F1	297	<-DEF	303	312	387	395				
F2	297	<-DEF	317	326	490	498				
Fb	250	251	307	321						
File_array										
File_data										
Filt_bw_int										
Filt_f1	266	402	406	407	426	560	561	572		
Filt_f11b										
Filt_f11r										
Filt_f1b										
Filt_f1r										
Filt_f2	266	505	509	510	529	618	619	627		
Filt_f22b										
Filt_f22r										
Filt_f2b										
Filt_f2r										
Gal_cyc_frg	277	281								
Gf	87	281	307	321						
Gpio	83	196	197	198	201	202	204	220	221	
Hpib	84									
I	804	805	806	807	810	811	812	813		
If1	262	266	305	306	383	387	395	425	426	55[illegible]
	594	595								
If2	264	266	319	320	486	490	498	528	529	617
	639	640								
[illegible]	378	402	406	407	409	483	505	509	510	51[illegible]
[illegible]	88	188	266	348	380	426	485	650	660	
[illegible]	89									
[illegible]	90									
[illegible]	193	<-DEF	194	208	209	210	211			
[illegible]	386	387	392	394	395	400	489	490	495	497
	498	503								
Max_x_axes										
Mmn	279	283	285							
Mn										
Mult_fun										
N	251	305	306	319	320	348	386	394	489	497
	785									
Nnn	215	253	254	255	256	785	907			
Ns										
Num_samp										
Num_samples	185	187	188	253	279	280				
Op										
[illegible]	[illegible]	306	312	314	319	320	326	328	34[illegible]	4[illegible]
	413	647	648	657	658	716	719	722	72[illegible]	[illegible]
	766	767	768	776	778	781				
Peak_value_data	276									
Peak_value_f1	379	406	407							
Peak_value_f11b										
Peak_value_f11r										
Peak_value_f1b										
Peak_value_f1r										
Peak_value_f2	484	509	510							
Peak_value_f22b										
Peak_value_f22r										
Peak_value_f2b										
Peak_value_f2r										
Product_f1	387	388	395	396						

Product_f2	490	491	498	499						
Q	365	367	380	485	719	766	785			
Qb	362	367	660	661						
Qc	593	594	595	638	639	640	645	648	649	650
	655	658	659	660						
Qccb	256	658								
Qccr	256	648								
Qj										
Qpsb	730	753	760	762	763	766				
Qpsr	683	706	713	715	716	719				
Qptb	749	751	753	756	758	760	762	763	766	
Qptr	702	704	706	709	711	713	715	716	719	
Qq	356	779	782	798						
Qqq	798	806	845	847	856	858	868			
Qr	361	362	365	650	651					
Qsb	144	731	734	753	760	762				
Qsr	143	684	687	706	713	715				
Qt	134 <-DEF		135	136	137	138	139	140	141	14[illegible]
	706	713	715	753	760	762				
Quotient	349	349								
R	799	820	829	844	855	867	946	947	948	949
Ra	691	693	694	695	697	700	706	713	738	740
	741	742	744	747	753	760				
Range_stored										
Rmar	781	782								
Rob	655	656	657							
Ror	645	646	647							
Rot	188									
Rotb	256	657								
Rotr	256	647								
[illegible]	192	208	209	210	211	213	215			
[illegible]	88	251	281							
Ssp										
Start	349	355	361	785						
Sum_f1	384	388	396	402						
Sum_f2	487	491	499	505						
Sys_del_bl										
Sys_del_red										
Ta_bl	188	767	768	847						
Ta_red	188	722	725	845						
Tat	731	734	753	760	766	767				
Tar	684	687	706	713	719	722				
Tb	845	847	849							
Test_data										
[illegible]										
Tot_angle_peak	341									
[illegible]										
[illegible]	207	208	209	210	211	214	280	282	288	38[illegible]
	381	382	386	387	394	395	411	485	489	49[illegible]
	497	498	514	843	845	847	849	850	854	856
	859	860	861	876	877	878	879			
	[illegible]	384	38[illegible]	38[illegible]	389	412	413	488	64[illegible]	[illegible]
[illegible]	28[illegible]	28[illegible]	285	286						
[illegible]										
[illegible] variables										
[illegible]	[illegible]	[illegible]	[illegible]							
[illegible]	[illegible]	[illegible]	9[illegible]	9[illegible]	90[illegible]	909	9[illegible]4	9[illegible]		
[illegible]	8[illegible]									

```
*   I/O Path Names
@Buf                     194    200    206
@Buffer                  285    877
@File                    909    913    914    925    930    947
@Gpio                    145    206

*   Line Labels
A_to_d_reset
Arc_t                    672 <-DEF
Buffer_array
Bw_label
Check_stat               290    874 <-DEF
Check_stat_r             910    943 <-DEF
Comments                  19 <-DEF
Comp_angle               176    336 <-DEF
Con_f1                   374 <-DEF
Con_f2                   479 <-DEF
Constants
Disp_con
Disp_data
Disp_data_1
Disp_data_2
Disp_out                  81    179    788 <-DEF    892
Dma_transfer             159    190 <-DEF
Doppler_cor
Env_f1                   420 <-DEF
Env_f2                   521 <-DEF
Err_rout                  77    886 <-DEF
File_array               167    922 <-DEF
File_data                160    895 <-DEF
Filt_bw_int              155    246 <-DEF
Index
Initialize                74 <-DEF
Main                     148 <-DEF
Mult_fun                 174    293 <-DEF
Num_samp                 150    182 <-DEF
Range_stored
Test                     268 <-DEF
Test_data
Var_list

*   Line Numbers
    [illegible]
```

221		
226		
240		
245		
249		
363	787	
372		
390		
524		
526		
540		
546		
548		
562		
571	567	
578		
600		
626	[illegible]	
634		
[illegible]		
64[illegible]		
679		
68[illegible]		
[illegible]		
7[illegible]6	66[illegible]	668
729		
738		
76[illegible]	[illegible]	[illegible]
[illegible]		
[illegible]		
82[illegible]		
[illegible]		
[illegible]		
[illegible]		
[illegible]		
[illegible]		
[illegible]	[illegible]	
[illegible]		
[illegible]		
[illegible]		
[illegible]		
1274		

[illegible]

```
!BRL_E_IR
!::::::::::::::::::::::::::::::::::::::::::::::::::
Comments:!PROGRAM FOR DATA ACQUISITION AND
         !DATA PROCESSING OF RANGE DATA.
!___________________________________________________
         !This program uses the difference
         !method for determining the amplitude
         !for f1 & f2.
         !Graphing is included for 200 enve-
         !lopes/graph. # of graphs depends on
         !the number os Num_samples.
         !Parameters of consideration: Ratios
         !of f2/f1, degrees/count red(Dpcr),
         !The phase correction, doppler
         !effect is included.
         !The parabolic fit is used to deter-
         !mine the location of the peak using
         !the greater of the amplitudes of f1
         !& f2. The phase correction is
         !independent for the red & blue.
         !AD Interface - Switch position NORMAL.
         PRINTER IS 1
         PRINT CHR$(12)
         PRINT TABXY(9,6),"RANGE PROGRAM"
         WAIT
         PRINT CHR$(12)
         PRINT TABXY(3,15),"
         !::::::::::::::::::::::::::::::::::::::::
Index    !INDEX TO ROUTINES
         !________________________________________
         !Comments
         !Index
         !Initialize
         !Constants
         !Variables
         !Menu
         !Num_samples
         !Dma_transfer
         !Buffer
         !Compare
         !Buffer array
         !Peak data
                         ::::::::::::::::::::::
```

```
115   GRAPHICS OFF
116   RAD
117   ON KEY 4 LABEL "GRAPH",15 GOSUB Disp_out
118   ENABLE
119   Gpio=12
120   Hpib=704
121 !::::::::::::::::::::::::::::::::::::::::::::
123 Constants:!
124 !____________________________________________
126      Sf=36000 !Sample frequency
127      Gf=3000 !galvo frequency set by clock
128      K1=12  !samples at f1
129      K2=6   !samples at f2
130      K3=4   !samples at f3
131      Sys_del_red=-0!-3 for data acquisition
132                    !+0 for Test_data
134      Sys_del_bl=-0 !-3 for data acquisition
135                    !+0 for Test_data
137      !Signal generator frequency 576.000KHz
138 !::::::::::::::::::::::::::::::::::::::::::::
139 Var_list:!Variable list
140 !____________________________________________
141      !Num_samp : number of samples to take at 36kHz rate
142      !Fb : filter bandwidth
143      !N : INT(Sf/fb)
144      !Ns :INT (Num_samples/4)
145      !Br( ) : array, sampled data, red
146      !Bl( ) : array, sampled data, blue
147      !If1 : interpolation factor for f1
148      !If2 : interpolation factor for f2
149      !F1( ) : convolution multipling function for f1
150      !F2( ) : convolution multipling function for f2
151      !Start : starting point, determined by N
152      !Qr : starting sampled data point for next K1
153           !interval, including doppler correction, red.
154      !Qb : same as Qr except, blue
155      !Xx : Xx=1, loop for red;Xx=2 loop for blue
156      !B1( ) : spare input
157      !B2( ) : spare input
158      !Filt_f1(J) : convolution elements in K1 interval, f1
159      !Filt_f2(J) : convolution elements in K1 interval, f2
160      !B1(P) : average of B1( ) in K1 interval
161      !B2(P) : average of B2( ) in k2 interval
162      !P : K1 interval of computation
163      !Ror : running sum of doppler correction, red
164      !Rob : running sum of doppler correction, blue
165      !Rotr(P) : running sum stored as a function of P
166      !Rotb(P) : running sum stored as a function of P
167      !Occr(P) : doppler correction for respective K1 interval, red
168      !Occb(P) : doppler correction for respective K1 interval, blue
169      !Qpsr : quadrant past, red
170      !Qpsb : quadrant past, blue
171      !Qptr : quadrant present, red
172      !Qptb : quadrant present, blue
173      !Qsr : running sum of quadrants, red
174      !Qsb : running sum of quadrants, blue
175      !Tar : total angle red, K1 interval
176      !Tab : total angle blue, K1 interval
177      !Ta_red(P) : total angle red, P K1 interval
178      !Ta_bl(P) : total angle blue, P K1 interval
179   !Whole quadrant update table
```

```
180   DIM Qt(4,4)
181   Qt(1,2)=1
182   Qt(1,4)=-1
183   Qt(2,1)=-1
184   Qt(2,3)=1
185   Qt(3,2)=-1
186   Qt(3,4)=1
187   Qt(4,1)=1
188   Qt(4,3)=-1
189   Qsr=10 !Quadrant sum red starts at 10
190   Qsb=10 !Quadrant sum blue starts at 10
191   ASSIGN @Gpio TO 12
192   !PRINT "     REGISTER STATUS BEFORE DMA"
193   !GOSUB Check_stat
194 !::::::::::::::::::::::::::::::::::::::::::::::
195 Main:! Main program
196 !_____________________________________________
197   PRINT CHR$(12)
198   GOSUB A_to_d_reset
199   GOSUB Range_stored
200   BEEP
201   GOSUB Mult_fun      !Generate multiplier
202                       !functions.
203   BEEP
204   GOSUB Comp_angle    !Convolution, envelop detection, doppler correction,
205                       !& Arctan for red and blue
206   DISP
207   GOSUB Disp_out
208   GOTO 1
209 !::::::::::::::::::::::::::::::::::::::::::::::
210 Range_stored:!
211 !_____________________________________________
213  INPUT "RANGE DATA, Type R/r : STORED DATA?, Type S/s",Aa$
214   IF Aa$="R" OR Aa$="r" THEN
215      GOSUB Num_samp
216      !GOSUB Dma_transfer
217      GOSUB Test_data
219      GOSUB File_data
220      GOSUB Buffer_array
221      GOSUB Filt_bw_int
222      RETURN
223   END IF
224   IF Aa$="S" OR Aa$="s" THEN
225      GOSUB File_array
226      GOSUB Buffer_array
227      GOSUB Filt_bw_int
228      RETURN
229   END IF
230      BEEP
231      BEEP
232      BEEP
233   GOTO 213
234 !::::::::::::::::::::::::::::::::::::::::::::::
235 Num_samp: !Input the total number of samples
236 !_____________________________________________
237            !to be taken. Maximum of 32K
238   BEEP
239   INPUT "TOTAL NUMBER OF SAMPLES TO BE TAKEN?",Num_samples
240   Ns=INT(Num_samples/4)
241   ALLOCATE INTEGER B0(0:Ns),INTEGER B1(0:Ns)
242   ALLOCATE INTEGER B1(0:Ns),INTEGER B2(0:Ns)
```

```
243   ALLOCATE INTEGER Rotr(0:Ns),Rotb(0:Ns),Qccr(0:Ns),Qccb(0:Ns)
245   ALLOCATE REAL Ta_red(INT(Num_samples/K1)),Ta_bl(INT(Num_samples/K1)),Rot(I
NT(Num_samples/K1))
246   !Create an un-named buffer so greater than
247   !32k can be collected.
248   ASSIGN @Buffer TO BUFFER [Num_samples]
249   RETURN
250 Dma_transfer:!
251   CONTROL @Buffer,4;0
252   CONTROL Gpio,0;2
253   CONTROL Gpio,3;0
254   !SET TRANSFER LOW
255   CONTROL Gpio,2;3 !SET CLT0 TO 0, XFER 0
256   BEEP
257   DISP "       WAITING FOR RANGE TRIGGER"
258   TRANSFER @Gpio TO @Buffer;COUNT Num_samples
259   CONTROL Gpio,2;2 !SET CLT0 & CLT1 TO 1
260   CONTROL Gpio,1;3
261   !PRINT "       REGISTER STATUS AFTER DMA"
262   !GOSUB Check_stat
263   BEEP
264   RETURN
265 Filt_bw_int:!Input filter bandwidth in hertz
266   BEEP
267   INPUT "WHAT IS THE DESIRED FILTER BANDWIDTH IN HERTZ?",Fb
268   N=INT(Sf/Fb)
269   PRINT CHR$(12)
270   BEEP
271   INPUT "Real samples f1=12, interpolation factor?",If1
272   BEEP
273   INPUT "Real samples f2=6, interpolation factor?",If2
274   BEEP
275   ALLOCATE REAL Filt_f1(1:K1*If1),Filt_f2(1:K1*If2)
276   RETURN
277 Test:! Generate data - needs to be modified for this
278      !program
279   BEEP
280   INPUT "What is the Envelop Peak Amplitude?",Epa
281   BEEP
282   DISP "                    GENERATING DATA"
283   Peak_value_data=0
284   Gal_cyc_frg=200
285   Ab=0
286   ALLOCATE INTEGER Mmm(0:Num_samples-1)
287   FOR X=0 TO Num_samples-1 STEP 4
288     Ac=Epa*SIN((PI*(+Ab))/(6*Gal_cyc_frg)+(2.7)*SIN(2*PI*Ab*Gf/Sf))
289     FOR Y=X TO X+3
290       Mmm(Y)=INT(Ac)+128
291           !PRINT Y,Mmm(Y)
292       OUTPUT @Buffer USING "#,B";Mmm(Y)
293     NEXT Y
294     Ab=Ab+1
295   NEXT X
296   DISP
298   WAIT 5
299   RETURN
300 !::::::::::::::::::::::::::::::::::::::::::::::
301 Mult_fun: !Generation of the multiplying function.
302 !_______________________________________________
303          !Multiplying function will be (SIN(X)/(X))*COS(Y)
304          !PRINTER IS 705
```

```
305   !ALLOCATE REAL F1(0:(N*If1)).REAL F2(0:(N*If2))
306   DIM F1(0:2000),F2(0:2000)
307   RAD
308   BEEP
309    !Generate 1/2 multiplier function for F1
310   BEEP
311   DISP "Building multiplier function for F1"
312   F1(0)=1
313               !PRINT "F1(0)=";F1(0)
314   FOR P=1 TO N*If1
315     Aa=(PI*P)/(N*If1)
316     Bb=(Aa*2*Gf)/Fb
317               !PRINT "P=";P
318               !PRINT "N=";N*If1
319               !PRINT "(PI*P)/N=";Aa
320               !PRINT "(Aa*2*GF)/FB=";Bb
321     F1(P)=(SIN(Aa)/Aa)*COS(Bb)
322               !PRINT "F1(";P;")=";F1(P)
323   NEXT P
324   DISP "Building multiplier function for F2"
325    !Generate 1/2 of multiplier function for F2
326   F2(0)=1
327               !PRINT "F2(0)=";F2(0)
328   FOR P=1 TO N*If2
329     Aa=(PI*P)/(N*If2)
330     Bb=(Aa*4*Gf)/Fb
331               !PRINT "P=";P
332               !PRINT "N=";N
333               !PRINT "(PI*P)/N=";Aa
334               !PRINT "(Aa*4*GF)/FB=";Bb
335     F2(P)=(SIN(Aa)/Aa)*COS(Bb)
336               !PRINT "F2(";P;")=";F2(P)
337   NEXT P
338   RETURN
339 !
340 !........................................
341 !Convolution and envelop detection
342 !at K1 intervals for f1 and f2.
343 !........................................
344 !::::::::::::::::::::::::::::::::::::::::::
345 Comp_angle:!Filter, envelop detection,
348              !doppler correction and
349              !arctan for red & blue
350 !_____________________________________________
352   RAD
353   Tot_angle_peak=0
354   P=0        !Initializaton of array for the out-
355              !put angle for red and blue lasers.
356     !Determine first data point to start con-
357     !volution considering the value of N and
358     !the need of a + slope for f1 for synchr-
359     !onization.
360   Quotient=(N+1) DIV K1
361   Start=(Quotient+1)*12
362   BEEP
363   DISP "          C R U N C H I N G   D A T A"
364   PRINT "Start=";Start
365   Qq=0  !Initialize graph index. Increment
366         !Qq for each 200 computations
370   Qr=Start+2+Sys_del_red
371   Qb=Start+2+Sys_del_bl
```

```
372   FOR Xx=1 TO 2 !1=red,2=blue
374     IF Xx=1 THEN
375       Q=Qr
376     ELSE
377       Q=Qb
378     END IF
379 !:::::::::::::::::::::::::::::::::::::::::::::
380 Con_f1:!
381         !Convolution over K1 interval for
382         !F1
383 !_____________________________________________
384     J=1
385     Peak_value_f1=0
388     FOR X=Q TO Q+K1-1
392       FOR C=0 TO If1-1
393         Sum_f1=0
394         IF Xx=1 THEN    !Xx=1,Red:Xx=2,Blue
395           FOR M=X TO X+N
396             Product_f1=Br(M+1)*F1((M-X)*If1-C+If1)+Br(2*X-M)*F1((M-X)*If1+C)
397             Sum_f1=Sum_f1+Product_f1
398            ! PRINT Q;TAB(10);X;TAB(20);C;TAB(30);M;TAB(40);J;TAB(45);((M-X)*
If1+C);
399            !  PRINT TAB(50);((M-X)*If1-C+If1);
400            !  PRINT TAB(60);(2*X-M-1)
401           NEXT M
402         ELSE
403           FOR M=X TO X+N
404             Product_f1=Bl(M+1)*F1((M-X)*If1-C+If1)+Bl(2*X-M)*F1((M-X)*If1+C)
405             Sum_f1=Sum_f1+Product_f1
406            !  PRINT Q;TAB(10);X;TAB(20);C;TAB(30);M;TAB(40);J;TAB(45);((M-X)
*If1+C);
407            !  PRINT TAB(50);((M-X)*If1-C+If1);
408            !  PRINT TAB(60);(2*X-M-1)
409           NEXT M
410         END IF
411         Filt_f1(J)=Sum_f1
413         !PRINTER IS 705
414         !PRINT "Filt_f1(";J;"=)";Filt_f1(J)
417         !PRINTER IS 1
418         IF ABS(Filt_f1(J))>Peak_value_f1 THEN
419           Peak_value_f1=ABS(Filt_f1(J))
420         END IF
421         J=J+1
422       NEXT C
423     NEXT X
424 !:::::::::::::::::::::::::::::::::::::::::::::
425 Env_f1:!Envelop detection over K1
426         !interval for f1
427 !_____________________________________________
428     Diff_plus_f1=0
429     Diff_minus_f1=0
430    FOR E=If1+1 TO 5*If1+1
431       Diff_f1=Filt_f1(E)-Filt_f1(E+INT(If1*K1/2))
432       IF Diff_f1>Diff_plus_f1 THEN
433         Diff_plus_f1=Diff_f1
434       END IF
435       IF Diff_f1<Diff_minus_f1 THEN
436         Diff_minus_f1=Diff_f1
437       END IF
438            !PRINT "e=";E,"Diff_f1=";Diff_f1
439            !PRINT "Diff_plus_f1=";Diff_plus_f1
```

```
440           !PRINT "Diff_minus_f1=";Diff_minus_f1
441      NEXT E
442         !Value of Envelop at P interval for f1
443      IF Diff_plus_f1>ABS(Diff_minus_f1) THEN
444        Envelop_f1=Diff_plus_f1
445      ELSE
446        Envelop_f1=Diff_minus_f1
447      END IF
448 !::::::::::::::::::::::::::::::::::::::::::::
449 Con_f2:!
450         !Convolution over K1 interval for F2
451 !___________________________________________
452      J=1
453      Peak_value_f2=0
454      FOR X=Q TO Q+K2-1
455        FOR C=0 TO If2-1
456          Sum_f2=0
457          IF Xx=1 THEN    !Xx=1,Red:Xx=2,Blue
458            FOR M=X TO X+N
459              Product_f2=Br(M+1)*F2((M-X)*If2-C+If2)+Br(2*X-M)*F2((M-X)*If2+C)
460              Sum_f2=Sum_f2+Product_f2
461           !  PRINT Q;TAB(10);X;TAB(20);C;TAB(30);M;TAB(40);J;TAB(45);((M-X)
*If2+C);
462           !  PRINT TAB(50);((M-X)*If2-C+If2);
463           !  PRINT TAB(60);(2*X-M-1)
464            NEXT M
465          ELSE
466            FOR M=X TO X+N
467              Product_f2=Bl(M+1)*F2((M-X)*If2-C+If2)+Bl(2*X-M)*F2((M-X)*If2+C)
468              Sum_f2=Sum_f2+Product_f2
469           !  PRINT Q;TAB(10);X;TAB(20);C;TAB(30);M;TAB(40);J;TAB(45);((M-X)
*If2+C);
470           !  PRINT TAB(50);((M-X)*If2-C+If2);
471           !  PRINT TAB(60);(2*X-M-1)
472            NEXT M
473          END IF
474          Filt_f2(J)=Sum_f2
475          !PRINTER IS 705
476          !PRINT "Filt_f2(";J;"=)";Filt_f2(J)
477          !PRINTER IS 1
478          IF ABS(Filt_f2(J))>Peak_value_f2 THEN
479            Peak_value_f2=ABS(Filt_f2(J))
480          END IF
481          J=J+1
482        NEXT C
483      NEXT X
484 !::::::::::::::::::::::::::::::::::::::::::::
485 Env_f2:!Envelop detection over fract-
486         !ional interval of K1 for f2
487         !using 1/2 cycle difference
488 !___________________________________________
489      Diff_plus_f2=0
490      Diff_minus_f2=0
492      FOR E=If2+1 TO 5*If2+1
493        Diff_f2=Filt_f2(E)-Filt_f2(E+3*If2)
494        IF Diff_f2>Diff_plus_f2 THEN
495          Diff_plus_f2=Diff_f2
496        END IF
497        IF Diff_f2<Diff_minus_f2 THEN
498          Diff_minus_f2=Diff_f2
499        END IF
```

```
500      NEXT E
501        !Value of Envelop at P interval for f2
502      IF Diff_plus_f2>ABS(Diff_minus_f2) THEN
503        Envelop_f2=Diff_plus_f2
504      ELSE
505        Envelop_f2=Diff_minus_f2
506      END IF
507      !PRINT "Envelop_f2";Envelop_f2
510 !::::::::::::::::::::::::::::::::::::::::::::::::
511 Doppler_cor:!
512 !_______________________________________________
513 !...............................................
514 ! CORRECTION FOR THE DOPPLER EFFECT FOR RED
515 !                AND BLUE
516 !...............................................
517      IF ABS(Envelop_f1)>ABS(Envelop_f2) THEN
518        FOR E=If1+1 TO 5*If1+1
519          D2=Filt_f1(E+2)-Filt_f1(E+1)
520          D1=Filt_f1(E+1)-Filt_f1(E)
521         !PRINT "D2=";D2,"D1=";D1,"(D2-D1)=";D2-D1,"E=";E
522          IF D2=0 OR SGN(D1)+SGN(D2)=0 THEN
523            GOTO 526
524          END IF
525        NEXT E
526        Dsq=D2-D1
527        Ap=Filt_f1(E)
528        Bp=D1-Dsq/2
529        Cp=Dsq/2
530        Envelop_f11=(Ap-(Bp^2)/(4*Cp))
531        !PRINT "Envelop_f11=";Envelop_f11
532        Ee=E-Bp/(2*Cp)
533        !PRINTER IS 705
534  !!!! PRINT "Ee_f1=";Ee
535        PRINTER IS 1
536        Qc=0
537        IF Ee>4*If1+1 THEN Qc=-1
538        IF Ee<2*If1-1 THEN Qc=+1
539      ELSE
540        FOR E=If2+1 TO 5*If2+1
541          D2=Filt_f2(E+2)-Filt_f2(E+1)
542          D1=Filt_f2(E+1)-Filt_f2(E)
543          !PRINT "D2=";D2,"D1=";D1,"(D2-D1)=";D2-D1,"E=";E
544          IF D2=0 OR SGN(D1)+SGN(D2)=0 THEN
545            GOTO 548
546          END IF
547        NEXT E
548        Dsq=D2-D1
549        Ap=Filt_f2(E)
550        Bp=D1-Ds/2
551        Cp=Dsq/2
552        Envelop_f22=(Ap-(Bp^2)/(4*Cp))
553        !PRINT "Envelop_f22=";Envelop_f22
554        Ee=E-Bp/(2*Cp)
555        !PRINTER IS 705
556 !!!!  PRINT "Ee_f2=";Ee
557        PRINTER IS 1
558        Qc=0
559        IF Ee>4*If2+1 THEN Qc=-1
560        IF Ee<2*If2-1 THEN Qc=+1
561      END IF
562      IF Xx=1 THEN
```

```
563        Ror=Ror+Qc
564   !!!! PRINT "Ror=";Ror,
565        Rotr(P)=Ror
566        Qccr(P)=Qc
567        !PRINTER IS 705
568   !!!! PRINT "Qc=";Qc
569        PRINTER IS 1
570        Qr=Qr+Qc+K1
571   !!!! PRINT "Qr=";Qr
572      ELSE
573        Rob=Rob+Qc
574   !!!! PRINT "Rob=";Rob
575        Rotb(P)=Rob
576        Qccb(P)=Qc
577        !PRINTER IS 705
578 !!!!   PRINT "Qc=";Qc
579        PRINTER IS 1
580        Qb=Qb+Qc+K1
581 !!!!   PRINT "Qb=";Qb
582        PRINT
583      END IF
584      E_f1=Envelop_f1
585      E_f2=Envelop_f2
586 !!!!PRINT "Envelop_f2/Envelop_f1=";Envelop_f2/Envelop_f1
587 !::::::::::::::::::::::::::::::::::::::::::::::::::
588 Arc_t:!Computation of the angle from the
589        !arctan(Envelop_f2/Envelop_F1) and
590        !counting of the whole quadrants
591 !______________________________________________
592        BEEP 500,.2
593      PRINTER IS 1
594      DEG
595      IF Xx=1 THEN ! Arc_t for Red laser
596        IF E_f1=0 THEN !Take care of divide by zero
597          IF Qpsr=1 OR Qpsr=3 THEN
598            Tar=(Qsr)*90+90
599            GOTO 634
600          ELSE
601            Tar=(Qsr)*90
602            GOTO 634
603          END IF
604        END IF
605        Ra=E_f2/E_f1
606        !PRINTER IS 705
607 !!!!   PRINT Ra
608        PRINTER IS 1
609        !Determine Quadrant & Total_angle(P)_
610        IF ABS(Ra)>=60 THEN
611          IF SGN(Ra)=1 THEN
612            Ra=60
613          ELSE
614            Ra=-60
615          END IF
616        END IF
617        IF SGN(Ra)=1 THEN !Plus Ratio
618          IF SGN(E_f1)=1 THEN ! Deno plus
619            Qptr=1
620          ELSE
621            Qptr=3
622          END IF
623          Tar=(Qt(Qpsr,Qptr)+Qsr)*90+ATN(Ra)-900
```

```
624         ELSE
625           IF SGN(E_f1)=1 THEN
626             Qptr=4
627           ELSE
628             Qptr=2
629           END IF
630           Tar=(Qt(Qpsr,Qptr)+Qsr)*90+90+ATN(Ra)-900
631         END IF
632         Qsr=Qt(Qpsr,Qptr)+Qsr
633         IF P>1 THEN Qpsr=Qptr
634         !RINTER IS 705
635 !!!!    PRINT P,PROUND(Tar,-2),Qpsr,Qptr,B1(Q),B1(P)
636         PRINTER IS 1
638         PRINT
639         Ta_red(P)=Tar
641 !!!!    PRINT P,"Ta_red=";PROUND(Ta_red(P),-2),"E_F1=";E_f1,"E_F2=";E_f2
642         PRINTER IS 1
643       ELSE!Arc_t for blue laser
644         IF E_f1=0 THEN !Take care of divide by zero
645           IF Qpsb=1 OR Qpsb=3 THEN
646             Tab=(Qsb)*90+90
647             GOTO 679
648           ELSE
649             Tab=(Qsb)*90
650             GOTO 679
651           END IF
652         END IF
653         Ra=E_f2/E_f1
654         !Determine Quadrant & Total_angle(P)_
655         IF ABS(Ra)>=60 THEN
656           IF SGN(Ra)=1 THEN
657             Ra=60
658           ELSE
659             Ra=-60
660           END IF
661         END IF
662         IF SGN(Ra)=1 THEN !Plus Ratio
663           IF SGN(E_f1)=1 THEN ! Deno plus
664             Qptb=1
665           ELSE
666             Qptb=3
667           END IF
668           Tab=(Qt(Qpsb,Qptb)+Qsb)*90+ATN(Ra)-900
669         ELSE
670           IF SGN(E_f1)=1 THEN
671             Qptb=4
672           ELSE
673             Qptb=2
674           END IF
675           Tab=(Qt(Qpsb,Qptb)+Qsb)*90+90+ATN(Ra)-900
676         END IF
677         Qsb=Qt(Qpsb,Qptb)+Qsb
678         IF P>1 THEN Qpsb=Qptb
679        !PRINTER IS 705
680         PRINT
682 !!!!    PRINT P,PROUND(Tab,-2),Qpsb,Qptb,B1(Q),B1(P)
683         PRINTER IS 1
685         Ta_bl(P)=Tab
686 !!!!    PRINT P,"Ta_bl=";PROUND(Ta_bl(P),-2),"E_F1=";E_f1,"E_F2=";E_f2
687       END IF!For red or blue
688       PRINTER IS 1
```

```
689    RAD
690    NEXT Xx
691    RAD
692    PRINT
693      !This completes the angle computation
694      !for the red and blue for this K1 interval P
695    P=P+1
696    PRINT P
698      !Test to increment Qq or not
699    IF P=0 THEN
700      Qq=0
701    ELSE
702      Rmdr=P MOD 199     !P starts at 0
703      IF Rmdr=0 THEN Qq=Qq+1
704    END IF
705    !Q>Ns-48, either red/blue will exit to Main
706    IF Q>=Ns-48 THEN RETURN
707    GOTO 372
708 Disp_out:!Graph data
709    DUMP DEVICE IS 705
710    PRINTER IS 705
711    PEN 2
712 !!PRINT CHR$(12);    !Clear alpha & form feed
713    DISP
714    GINIT                !Initialize
715    GRAPHICS ON          !Raster on
716    FOR Qqq=0 TO Qq !Graph index
717      FOR R=1 TO 2 !red=1, blue=2
718        PEN 2
719        WINDOW -7,50,-500,500 !Set window
720        AXES 10,100
721        LORG 6
722        FOR I=0 TO 50 STEP 10
723          MOVE I,0
724          LABEL Qqq*200+I
725        NEXT I
726       !
727        LORG 8
728        FOR I=-400 TO 400 STEP 100
729          MOVE 0,I
730          LABEL I
731        NEXT I
732       !
733        LORG 5
734        MOVE 25,475
735        PEN 6
736        LABEL "ANGLE AS A FUNCTION OF ENVELOP SAMPLES"
737        MOVE 18,425
738        IF R=1 THEN
739        PEN 2
740        LABEL "RED"
741        MOVE 18,-400
742        LABEL Name$
743        PEN 6
744        END IF
745        IF R=2 THEN LABEL "BLUE"
746        MOVE 18,-400
747        LABEL Name$
748        PEN 2
749        MOVE -4,0
750        LORG 6
```

```
751       LABEL "Samp"
752       LORG 5
753       MOVE 25,-475
754       LABEL Title$;"ENVELOP SAMPLE RATE, 3KHZ"
755       PEN 0
756       MOVE 0,0
757       PEN 2
758       FOR X=0 TO 50  !graph data
759         IF R=1 THEN
760           Tb=Ta_red(Qqq*200+X+4)-Ta_red(4)
761         ELSE
762           Tb=Ta_bl(Qqq*200+X+4)-Ta_bl(4)
763         END IF
764         DRAW X,Tb
765       NEXT X
766       PEN 0
767       MOVE 0,0
768       PEN 0
769       PAUSE
770       !DUMP GRAPHICS
771       !PRINT CHR$(12)
772       GCLEAR
773     NEXT R
774   NEXT Qqq
775   ALPHA ON
776   PRINTER IS 1
777   DISP "PAUSE"
778   PAUSE
779   RETURN
780 !:::::::::::::::::::::::::::::::::::::::::::::::
781 Err_rout:  !Routines for error recovery
782 !_______________________________________________
783   BEEP
784   BEEP
785   BEEP
786   DISP ERRM$
787   PAUSE
788   GOSUB Disp_out
789   PAUSE
790 !:::::::::::::::::::::::::::::::::::::::::::::::
791 Buffer_array:!Transfer of data from buffer to          array.
792 !_______________________________________________
793      PRINT CHR$(12)
794      DISP "TRANSFERRING DATA FROM BUFFER TO 4 ARRAYS"
795    CONTROL @Buffer,5;1
796    FOR X=1 TO Ns-1
797      ENTER @Buffer USING "#,B";Zzz
798      Br(X-1)=Zzz-128
799      ENTER @Buffer USING "#,B";Zzz
800      Bl(X-1)=Zzz-128
801      ENTER @Buffer USING "#,B";Zzz
802      B1(X-1)=Zzz-128
803      ENTER @Buffer USING "#,B";Zzz
804      B2(X-1)=Zzz-128
805           !PRINT X-1,Br(X-1),Bl(X-1),B1(X-1),B2(X-1)
806    NEXT X
807    DISP "TRANSFER COMPLETE"
808    WAIT 2
809    PRINT CHR$(12)
810   RETURN
811 !:::::::::::::::::::::::::::::::::::::::::::::::
```

```
812 File_data: !Transfer of data from Buffer
813             !to disk
814 !_____________________________________________
815   BEEP
816   DISP "INSERT A FORMATTED DATA DISK! - PRESS CONT TO CONT"
817   PAUSE
818   INPUT "NAME OF DATA FILE TO BE CREATED?",Name$
819   IF Name$="" THEN 818
820   BEEP
821   DISP "CREATING A DATA FILE"
822     !Record length is 1
823   CREATE BDAT Name$&":INTERNAL",Num_samples,1
824     !Assign an I/O path
825   ASSIGN @File TO Name$&":INTERNAL"
826   PRINT CHR$(12)
827   DISP "TRANSFERRING DATA FROM BUFFER TO FILE"
828   TRANSFER @Buffer TO @File;COUNT Num_samples
829   WAIT 5
830   DISP "TRANSFER COMPLETE"
831   WAIT 5
832   DISP
833   RETURN
834 !:::::::::::::::::::::::::::::::::::::::::::::
835 File_array:  !Transfer from file to array
836 !_____________________________________________
837     BEEP
838     PRINT CHR$(12)
839     DISP "INSERT DATA DISK -- PRESS CONT TO CONT"
840     PAUSE
841     CAT
842     BEEP
843     INPUT "WHAT FILE?",Name$
844     INPUT "Rec/File for file?",Num_samples
845     GOSUB 240
846     ASSIGN @File TO Name$&":INTERNAL"
847       !Reset file pointer to 1
848     CONTROL @File,5;1
849       !Reset buffer pointer to 1
850     CONTROL @Buffer,5;1
851     DISP "TRANSFERRING FROM DATA FILE TO BUFFER ARRAY"
852     TRANSFER @File TO @Buffer;COUNT Num_samples
853     DISP "TRANSFER COMPLETED"
854       !Reset buffer pointer to 1
855     CONTROL @Buffer,5;1
856       !Close @file
857     ASSIGN @File TO *
858     WAIT 2
959     PRINT CHR$(12)
860     DISP
861   RETURN
862 !:::::::::::::::::::::::::::::::::::::::::::::
863 A_to_d_reset:  !
864 !_____________________________________________
865     !RESET DATA TRANSFER ELECTRONICS
866     CONTROL Gpio,2;2 !SET CTL0 & CTL1 TO 0
867     CONTROL Gpio,2;0 !SET CTL0 TO 1 & CTL1 TO 0
868     CONTROL Gpio,2;2 !SET CTL0 & CTL1 TO 1
869     !END RESET
870     RETURN
876 !:::::::::::::::::::::::::::::::::::::::::::::
1180 Test_data:! Generate test data
```

```
1181 !--------------------------------------------------
1183    !PRINTER IS 705
1184 PRINT CHR$(12)
1185 DISP
1187 BEEP
1188 INPUT "What is the Envelop Peak Amplitude?",Epa
1189 BEEP
1190 DISP "                              GENERATING DATA"
1191 Peak_value_data=0
1192 Gal_cyc_frq=200
1193 Ab=0
1194 ALLOCATE INTEGER Mmm(0:Ns*4-1)
1195 FOR X=0 TO Ns*4-1 STEP 4
1196   Ac=Epa*SIN((PI*(+Ab))/(6*Gal_cyc_frq)+2.7*SIN(2*PI*Ab*Gf/S))
1199   FOR Y=X TO X+3
1200     Mmm(Y)=INT(Ac)+128
1201          !PRINT Y,Mmm(Y)
1202     OUTPUT @Buffer USING "#,B";Mmm(Y)
1203   NEXT Y
1204   Ab=Ab+1
1205 NEXT X
1208 DISP
1209 RETURN
1216 END
```

Cross Reference <<<<<

Numeric Variables

[illegible]_tc_c_reset									
Ha	315	316	321	329	330	335			
H[illegible]	285	288	294	1193	1196	1204			
H[illegible]	288	290	1196	1200					
H[illegible]	527	530	549	552					
[illegible]	242	802							
[illegible]_peak									
[illegible]									
[illegible]	242	804							
[illegible]_peak									
[illegible]									
[illegible]	316	321	330	335					
Bo[illegible]									
[illegible]									
[illegible]									
[illegible]	241	404	467	800					
B[illegible]	528	530	532	550	552	554			
Br	241	396	459	798					
Buffer_array									
Bw_label									
C	392	396	404	422	455	459	467	482	
Check_stat									
Check_stat_r									
Comp_angle									
Con_f2									
Cp	529	530	532	551	552	554			
Csbf1									
Csbf2									
Csrf1									
Csrf2									
D1	520	522	526	528	542	544	548	550	
D2	519	522	526	541	544	548			
Diff_f1	431	432	433	435	436				
Diff_f2	493	494	495	497	498				
Diff_minus_f1	429	435	436	443	446				
Diff_minus_f2	490	497	498	502	505				
Diff_plus_f1	428	432	433	443	444				
Diff_plus_f2	489	494	495	502	503				
Disp_con									
Disp_data									
Disp_data_1									
Disp_data_2									
Disp_out									
Dma_transfer									
Dpcb									
Dpcr									
Ds	550								
Dsq	526	528	529	548	551				
E	430	431	441	492	493	500	518	519	5[illegible]
	527	532	540	541	542	547	549	554	
E_f1	584	596	605	618	625	644	653	663	6[illegible]
E_f2	585	605	653						
Ee	532	537	538	554	559	560			
Endcat									
Envelop_f1	444	446	517	584					
Envelop_f11	530								
Envelop_f2	503	505	517	585					

AD-A179 742 LASER BALLISTIC SENSOR DEVELOPMENT(U) BOEING AEROSPACE CO SEATTLE WA C R POND ET AL JAN 87 BRL-CR-563 DAAK11-84-C-0095 2/2

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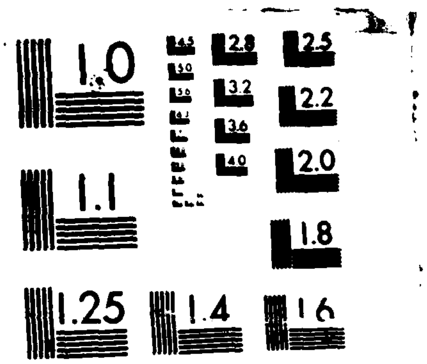

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

Envelop_f22	552									
Epa	280	288	1188	1196						
Err_rout										
F1	306	<-DEF	312	321	396	404				
F2	306	<-DEF	326	335	459	467				
Fb	267	268	316	330						
File_array										
File_data										
Filt_bw_int										
Filt_f1	275	411	418	419	431	519	520	527		
Filt_f11b										
Filt_f11r										
Filt_f1b										
Filt_f1r										
Filt_f2	275	474	478	479	493	541	542	549		
Filt_f22b										
Filt_f22r										
Filt_f2b										
Filt_f2r										
Gal_cyc_frg	284	288	1192	1196						
Gf	127	288	316	330	1196					
Gpio	119	252	253	255	259	260	866	867	868	
Hpib	120									
I	722	723	724	725	728	729	730	731		
If1	271	275	314	315	392	396	404	430	431	518
	537	538								
If2	273	275	328	329	455	459	467	492	493	540
	559	560								
J	384	411	418	419	421	452	474	478	479	481
K1	128	245	275	360	388	431	570	580		
K2	129	454								
K3	130									
Kk										
M	395	396	401	403	404	409	458	459	464	466
	467	472								
Max_x_axes										
Mmm	286	290	292	1194	1200	1202				
Mn										
Mult_fun										
N	268	314	315	328	329	360	395	403	458	466
Nnn										
Ns	240	241	242	243	706	796	1194	1195		
Num_samp										
Num_samples	239	240	245	248	258	286	287	823	828	844
	852									
Op										
[illegible]	314	315	321	323	328	329	335	337	354	565
	566	575	576	633	639	678	685	695	696	699
	702									
Peak_value_data	283	1191								
Peak_value_f1	385	418	419							
Peak_value_f11b										
Peak_value_f11r										
Peak_value_f1b										
Peak_value_f1r										
Peak_value_f2	453	478	479							
Peak_value_f22b										
Peak_value_f22r										
Peak_value_f2b										
Peak_value_f2r										
Product_f1	396	397	404	405						

Product_f2	459	460	467	468						
Q	375	377	388	454	706					
Qb	371	377	580							
Qc	536	537	538	558	559	560	563	566	570	573
	576	580								
Qccb	243	576								
Qccr	243	566								
Qj										
Qpsb	645	668	675	677	678					
Qpsr	597	623	630	632	633					
Qptb	664	666	668	671	673	675	677	678		
Qptr	619	621	623	626	628	630	632	633		
Qq	365	700	703	716						
Qqq	716	724	760	762	774					
Qr	370	375	570							
Qsb	190	646	649	668	675	677				
Qsr	189	598	601	623	630	632				
Qt	180	<-DEF	181	182	183	184	185	186	187	188
	623	630	632	668	675	677				
Quotient	360	361								
R	717	738	745	759	773					
Ra	605	610	611	612	614	617	623	630	653	655
	656	657	659	662	668	675				
Range_stored										
Rmdr	702	703								
Rob	573	575								
Ror	563	565								
Rot	245									
Rotb	243	575								
Rotr	243	565								
S										
Sf	126	268	288	1196						
Ssp										
Start	361	364	370	371						
Sum_f1	393	397	405	411						
Sum_f2	456	460	468	474						
Sys_del_bl	134	371								
Sys_del_red	131	370								
Ta_bl	245	685	762							
Ta_red	245	639	760							
Tab	646	649	668	675	685					
Tar	598	601	623	630	639					
Tb	760	762	764							
Test_data										
Tic_m_x										
Tot_angle_peak	353									
Tt										
X	287	289	295	388	395	396	403	404	423	454
	458	459	466	467	483	758	760	762	764	765
	796	798	800	802	804	806	1195	1199	1205	
Xx	372	374	394	457	562	595	690			
Y	289	290	292	293	1199	1200	1202	1203		
Z										
Zzz	797	798	799	800	801	802	803	804		

* String Variables

Aa$	213	214	224					
Name$	742	747	818	819	823	825	843	846
Title$	754							

* I/O Path Names

```
@Buf
@Buffer            248   251   258   292   795   797   799   801   803   828
                   850   852   855  1202
@File              825   828   846   848   852   857
@Gpio              191   258

*    Line Labels
A_to_d_reset       198   863 <-DEF
Arc_t              588 <-DEF
Buffer_array       220   226   791 <-DEF
Bw_label
Check_stat
Check_stat_r
Comments            11 <-DEF
Comp_angle         204   345 <-DEF
Con_f1             380 <-DEF
Con_f2             449 <-DEF
Constants          123 <-DEF
Disp_con
Disp_data
Disp_data_1
Disp_data_2
Disp_out           117   207   708 <-DEF   788
Dma_transfer       250 <-DEF
Doppler_cor        511 <-DEF
Env_f1             425 <-DEF
Env_f2             485 <-DEF
Err_rout           113   781 <-DEF
File_array         225   835 <-DEF
File_data          219   812 <-DEF
Filt_bw_int        221   227   265 <-DEF
Index               81 <-DEF
Initialize         109 <-DEF
Main               195 <-DEF
Mult_fun           201   301 <-DEF
Num_samp           215   235 <-DEF
Range_stored       199   210 <-DEF
Test               277 <-DEF
Test_data          217  1180 <-DEF
Var_list           139 <-DEF

*    Line Numbers
      1            208
      4
      5
      9
     11
     13
     17
     24
    157
    174
    180
    188
    194
    196
    202
    213            233
    214
    220
    221
```

226		
240	845	
245		
249		
363		
372	707	
390		
524		
526	523	
540		
546		
548	545	
562		
571		
576		
600		
626		
634	599	602
635		
648		
679	647	650
686		
691		
716		
729		
736		
763		
816		
818	819	
820		
827		
830		
858		
884		
895		
902		
907		
911		
951		
1254		
1274		

* SUB Subprograms
Endcat

Unused entries = 3

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